A COMPARISON OF TWO SUBJECT-CONTROLLED ATTITUDE MEASURES DURING SOMATOGRAVIC ILLUSION EXPOSURE

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A COMPARISON OF TWO SUBJECT-CONTROLLED ATTITUDE MEASURES DURING SOMATOGRAVIC ILLUSION EXPOSURE

John F. Thompson

St. Mary's University, 1988

Supervising Professor: Antonio J. Dieck, Ph.D.

The United States Air Force School of Aerospace Medicine (USAFSAM) has a requirement for a performance evaluation and comparison of two subject-controlled attitude indicators during exposure to the somatogravic or posturogravic illusion. This illusion is well known for giving aircraft pilots a false sensation of excessive pitch-up during takeoff. With a lack of visual stimuli, the pilot misinterprets the resultant gravitoinertial force vector as approximating the vertical force vector of gravity. Accidents occur when pilots adjust to what they feel is level flight, when they are, in fact, pitched down toward the ground. The USAFSAM Vertifuge (spatial disorientation device) was used to generate this illusion in 16 subjects (8 experienced pilots and 8 nonpilots) by varying gravitoinertial and actual (cabin) pitch positions. Each subject rode the Vertifuge twice. During one session, the subject used a canopy-mounted downpointer

Cont.

to estimate position in space relative to the ground, and in the other session the subject used a joystick-controlled inside-out aircraft attitude indicator. As expected, the results clearly indicate that the canopy-mounted downpointer is better at quantifying the somatogravic illusion in this Vertifuge study. Furthermore, it is apparent that there are no significant differences in performance between pilots and nonpilots using either device.

PREFACE

The following thesis deals with an evaluation of two subject-controlled attitude measures used by the United States Air Force School of Aerospace Medicine at Brooks Air Force Base, San Antonio, Texas. These devices are used in the study and quantification of spatial disorientation illusions, which adversely affect the ability of aircraft pilots to safely control their aircraft in flight. The United States Air Force is interested in which device may more accurately quantify illusions, and therefore, be of more value in the research and training aspects of spatial disorientation. It is hoped that this thesis will satisfy these important requirements and provide useful information for further study in this topical area.

Preliminary research and design formulation began in November 1987, data collection started in February 1988, the thesis went to committee on 12 July 1988, and the committee met and gave final approval on 20 July 1988.

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The author wishes to express his sincere thanks to the following individuals for their assistance in the completion of this thesis: Dr. Fred Previc, Dr. Kent Gillingham, Dr. Bill Storm, Mr. Bill Ercoline, and Ms. Carolyn Oakley from the United States Air Force School of Aerospace Medicine; and Dr. Abe Yazdani and Dr. Willie Silva of St. Mary's University.

A most special thank you to the two individuals who provided the most help and support over the entire project, from initial idea to final printing. Ms. Fran Greene, who shared her ideas, recommendations, and even her office; and Dr. Antonio Dieck, supervising professor.

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Rarely does a week go by without a tragic aircraft accident. From the most high technology military jet fighters right down to the Piper Cub, none are "crash-resistant" or completely and infallibly automated. Aircraft accidents happen for many reasons: mechanical failure, structural failure, weather, and human error. With respect to human error, man has not adapted to an airborne environment; rather, he is a ground-oriented creature not particularly well-suited to perceiving the acceleration, velocity, and attitude changes associated with aircraft operations (Gillingham and Wolfe [1985]). Dowd [1974] reports that even though a highly sophisticated inertial guidance system has evolved phylogenetically in man, it does not provide enough information and often produces erroneous information in the flying environment.

One major cause of operational aircraft accidents are illusions which result in spatial disorientation, directly attributable to the unusual parameters encountered in flight. Kirkham et. al.[1978] define aviation spatial disorientation as "an incorrect self-appraisal of the attitude or motion of the pilot and his plane with respect to the earth" (p. 1080). This class of effects generally prevents the pilot from correctly determining his/her position in space. In general pilot "lingo," and even in FAA publications, spatial disorientation is referred to as vertigo or pilot vertigo. Barnum and Bonner [1971] warn that as airspeeds and angular accelerations increase with modern-day aircraft, so will the incidence of spatial disorientation.

1.2 PURPOSE

The primary objective of this research was to evaluate different mechanisms for the continued study of spatial disorientation at the USAF School of Aerospace Medicine. Results of thi study may be applied to enhance future research and training, and accident investigation.

1.3 OVERVIEW OF THE THESIS

In this study, subjects were exposed to the somatogravic illusion, one in the class of spatially disorienting illusions. They were asked to indicate their subjective perception of pitch attitude (with respect to the ground) using two different subject-controlled attitude indicators. The purpose was to determine which device is more accurate in quantifying the illusion. Accuracy was defined by the deviation from the predicted gravitoinertial value, based on a previously tested model of the somatogravic illusion (which will be discussed in Chapter II). Chapter II is a literature review of the thesis topic area which moves from a general historical overview and description of spatial disorientation to a specific review of the somatogravic illusion and it's sensory components. Chapter III is the methodology section, covering subjects, apparatus, design, and specific procedures used in the present study. Chapter IV presents the experimental results in two separate formats: descriptive and inferential statistics. And finally, Chapter V provides a summary of the main conclusions of the thesis, a discussion of these results, and several recommendations for further research.

CHAPTER II

LITERATURE REVIEW

2.1 HISTORICAL PERSPECTIVE

One of the earliest references recognizing spatial disorientation as a problem encountered in the airborne environment appears in Jones [1919], who stated that:

> Without functioning internal ears, it is impossible for an individual to be a good birdman. In order to preserve the wonderful accuracy necessary in controlling such a delicate mechanism as the flying machine, he relies preeminently on his ear balance...(p. 24).

Jones [1919] stated further that "it is highly probable that many an aviator has gone to his death because, unknown to him, he did not possess a normal ear mechanism." As will be described, in actuality it is this "normal ear mechanism" (vestibular organ) which is the cause of the spatial disorientation aircraft accident (Nuttall [1958]).

Another historical example of spatial disorientation springs from the same era and thinking as Jones' statement [1919]. While writing on the history of instrument flight, Ercoline [1985] refers to the Wright brothers' practice of using a string as the first flight "instrument" to indicate attitude. An eight inch string was placed in the air stream in front of the pilot and when it extended straight back the pilot knew the plane was in level flight. Later instructors unfortunately taught their students to disregard these strings and trust their "feel of the ship." The "flying instinct" concept produced many dead pilots in World War I, when Americans first began flying in weather. Ercoline [1985] further quotes the famous 1920's "birdman," Major John A. Macready, who said:

> Few persons realize that flying is virtually impossible unless there is some exterior fixed point that the pilot may use to obtain a sense of balance or position. If there is no horizon, no light or any fixed object, a pilot cannot tell the position that the plane is in except from the instruments in the cockpit. I personally believe that if there is no fixed point or horizon, no one can tell his position, whether upside down, straight up, or crosswise, except when the force of gravity pulls him away from or toward the plane (p. 168).

As will be discussed, even the perceived gravitational force can, in some instances, be misleading and illusory.

2.2 SPATIAL DISORIENTATION

Spatial disorientation is a phenomenon in which aircrew members lose their capacity to accurately establish their position with respect to the earth. Many different spatially disorienting illusions have been identified over the years. It has been reported by Gillingham [1987] that from 1980 to 1986 a total of 69 USAF aircraft (approximately 17 percent of all mishaps) were lost due to some aspect of spatial disorientation.

This means the U.S. Air Force has an annual loss of approximately 10 aircraft, over 10 lives, and between $60 and $100 million in assets/training lost every year as a direct result of spatial disorientation. Spatial disorientation is not just a phenomenon of the high-performance aircraft of the 80's; during an eleven-year period beginning in 1958, 192 USAF pilots lost their lives in accidents attributable to spatial disorientation (Barnum and Bonner [1971]). As can be easily seen, spatial disorientation has been and is still a costly problem. Most aircraft involved in spatial disorientation accidents are fighters and jet trainers (84 percent), but other aircraft are affected as well. Additionally, it appears that pilot age and experience, and phase of flight have little to do with the incidence of spatial disorientation accidents (Barnum and Bonner [1971]).

Rayman's [1973] study of sudden incapacitation in flight shows that 26 out of 89 incidences, or 29 percent, were due to spatial disorientation. Sixteen of the cases resulted in fatalities and, as expected, most of the occurrences (23) occurred in fighter and jet trainer aircraft. Table 2.1 is taken from Rayman [1973]. In a follow-up study, Rayman and McNaughton [1983] surveyed the period from 1970 to 1980. Again, spatial disorientation was found to be "a major cause of aircraft accidents/incidents," even though it is probably an under-reported occurrence. Of the 25

Cause		Number of Cases
Loss of Consciousness		36
Spatial Disorientation)		26
Hypoxia)		19
Fumes in Cockpit)	Without Loss of	4
Airsickness)	Consciousness	1
Hyperventilation)		1
Coronary Insufficiency)		1
Otitis Media)		1
	Total =	89

Table 2.1 CAUSES OF SUDDEN INCAPACITATION IN FLIGHT
January 1966-November 1971
(Rayman [1973])

disorientation mishaps reported (14 of which were fatal), 20 involved fighters or jet trainers. Table 2.2 is taken from Rayman and McNaughton [1983].

Phase of Flight	No.
Bombing range over water	5
Bombing range, land	2
Takeoff at night or in clouds	8
Approach/land thru clouds/night	6
Intercepts, night/haze	3
Cruise	1
Total =	25

Table 2.2 PHASE OF FLIGHT AND SPATIAL DISORIENTATION, 1970-80
(Rayman and McNaughton [1983])

Yet another study of spatial disorientation accidents in the U.S. Air Force comes from Moser [1969], who reported 9% of the major flight accidents and 26% of the fatal accidents from 1964-1967 in the Aerospace Defense Command were attributable to spatial disorientation. Of these accidents, 91% involved pilots with more than 1000 flying hours, so the problem is evidently not solved by greater experience.

Clearly, spatial disorientation is an important military problem, since mostly high-performance aircraft are involved. However, general/civilian aviation is not exempt from spatial disorientation. Kirkham et. al.[1978] showed that spatial disorientation ranks as the third largest cause of fatal accidents in small, fixed-wing civilian aircraft, contributing to 16% of all such accidents. They suggest that further training be recommended for civilian pilots who, in many cases, do not understand the concepts and dangers of spatial disorientation.

A major program is underway at USAFSAM to develop a curriculum to train aircrews to recognize and cope with this class of illusions (Shifrin [1986]). During training programs, aircrews are exposed to spatially disorienting illusions on the USAFSAM Vertifuge. It is hoped that through periodic exposure and improved training techniques that an awareness and sensitization of this problem can be imparted on all flying personnel.

2.3 SENSORY FACTORS IN SPATIAL DISORIENTATION

Kirkham et. al.[1978] report that most of the incidents of spatial disorientation occurring in flight are due to inadequate or unreliable sensory information.

The visual and vestibular systems are critically important in maintaining proper orientation. In flight, pilots are often encountering situations which may exceed the capability of their senses to maintain proper awareness of their orientation in space. Pilots rely to a large extent on external visual cues when flying in "good weather," but the pilot may be forced to rely exclusively on "secondary orientation modalities" like the vestibular and proprioceptive systems in total darkness or "bad weather." Unfortunately, these systems often fail to provide accurate percepts regarding attitude and motion.

Malcolm [1984] states that orientation is primarily visual in nature, followed by vestibular, and finally proprioceptive and kinesthetic inputs (the "seat-of-the-pants" sensations). Within the vestibular system, the semicircular canals stabilize the eyes during head movement and sense angular acceleration, while the otolith organs provide a direction of the resultant G-vector through sensing linear acceleration. This resultant G-vector is further defined as a combination of gravity and any linear acceleration. These vestibular organs send their motion and orientation information to the cortex of the brain via the vestibular nucleus.

Dowd [1974] examined the causes of spatial disorientation by first describing the three main sensory systems which influence it: visual, proprioception, and vestibular. Vision is man's dominant sense. When adequate and correct visual stimuli are present (i.e., a well-defined horizon), pilots generally have no problems with spatial disorientation. Proprioceptive and tactile cues "provide information concerning the activity of skeletal muscular groups and of the relative position and movements of limbs" (p. 759). Loading from linear acceleration can affect these senses. For instance, a pilot being pressed back in his seat during a takeoff will "feel" himself and his aircraft being tilted back. The vestibular system stabilizes the head and eyes during body movement. The interaction of all of these mechanisms, especially if conflicting, can create an "imposing psychophysiological hodgepodge" (Nuttall [1958], p. 433). As previously stated, the organs involved in the vestibular system are the otoliths and the semicircular canals. The otoliths sense the attitude of the head relative to gravity and are generally analogous to the artificial horizon on the instrument panel. The semicircular canals sense angular acceleration. Both organs provide information to skeletal muscles involved in body stabilization.

As early as 1949, Clark and Graybiel identified visual cues as forming the basis for proper orientation during flight. If visual cues are deficient or illusory, then spatial disorientation may occur. Further, false or misleading nonvisual cues are normally suppressed if existing visual cues are adequate; if not, then rivalry between existing stimuli may incorrectly be resolved with grave results. Nuttall [1958] states that "normal visual perception, even in flight and when used appropriately, is almost 100% reliable, whereas labyrinthine sensations (vestibular) in flight are, on the contrary, almost 100% unreliable as a means of orientation in space" (p. 432). The vestibular system evolved to function on the stable platform of earth, but in the unstable sky it is the "perfect organ of perceptual confusion" (p. 432).

Modern instruments have not completely solved the problem of spatial disorientation (Braybrook [1987]). There are no instruments which have "the same unambiguous and convincing quality as the earth's horizon." This could be because the brain determines attitudinal orientation from the peripheral vision, not the central vision where most cockpit instrumentation is mounted (Braybrook [1987] and Malcolm [1984]). McNaughton [1985] defines peripheral vision as the "ambient mode" of vision. He claims it is noncritical and can easily be fooled or deceived. Interestingly, he views it as not exclusively visual, but "hard-wired" to the same terminals in the brain into which orientation information from our other senses of balance, proprioception, and hearing are fed. Instead of a mismatch between vision and the other senses, McNaughton identifies peripheral vision as one component of a multi-sense system of orientation.

2.4 THE SOMATOGRAVIC ILLUSION

Braybrook [1987] reports that the somatogravic illusion was first identified in the 1940's, when "a number of perfectly serviceable aircraft were flown into the ground, wings-level, immediately after takeoff" (p. 28). This illusion is a common spatially disorienting effect which gives an aircrew member "a false sensation of body tilt that results from perceiving as vertical the direction of a nonvertical resultant gravitoinertial force" (Gillingham, Shochat, and Fischer [1987]).

The illusion occurs during the absence of "good" visual stimuli and can easily be described in the following example. During a dark night takeoff, if there is an absence of visual pitch information, a pilot may confuse the true vertical (i.e., gravitational) vector with the vector caused by the addition of the inertial force resulting from the aircraft's acceleration and the force of gravity (i.e., gravitoinertial). If the pilot believes that the resultant gravitoinertial vector is the true vertical, then the pilot also believes that the aircraft is excessively pitched up. Any corrective action may place the aircraft in a shallow dive (the pilot believes he has corrected to be straight and level), potentially resulting in a collision with unseen land or water (Buley and Spelina [1970]). Figure 2.1 (Buley and Spelina [1970] and Figure 2.2 (Air Force Manual 51-37 [1986]) graphically represent the force vectors and pilot "feelings" associated with the somatogravic illusion. Cohen et. al.[1973] argue, in opposite fashion, that affected pilots could attribute a true excessive nose-up attitude exclusively to the illusion, allowing their airspeed to decay and causing a crash because they were too "aware" of the somatogravic illusion.

Barnum and Bonner [1971] report that 19% of USAF disorientation accidents occurred during the critical takeoff/departure phase of flight. Rayman and McNaughton [1983] present data showing that of 25 confirmed spatial disorientation accidents from 1970-80, 8 (32%) occurred during takeoff at night or in clouds (See Table 2.2).

The primary component of the somatogravic illusion is linear acceleration, which Clark and Graybiel [1949] define as a "change in velocity without a change in direction" (p. 93). Linear acceleration acting in the horizontal plane of a pilot and his aircraft and gravity acting on the vertical plane combine to produce the resultant gravitoinertial force vector (as illustrated

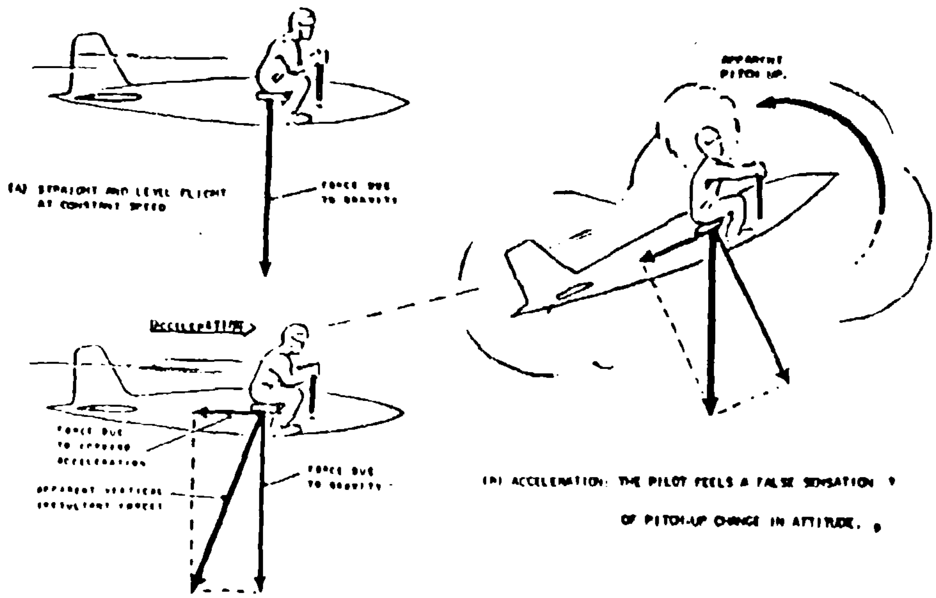
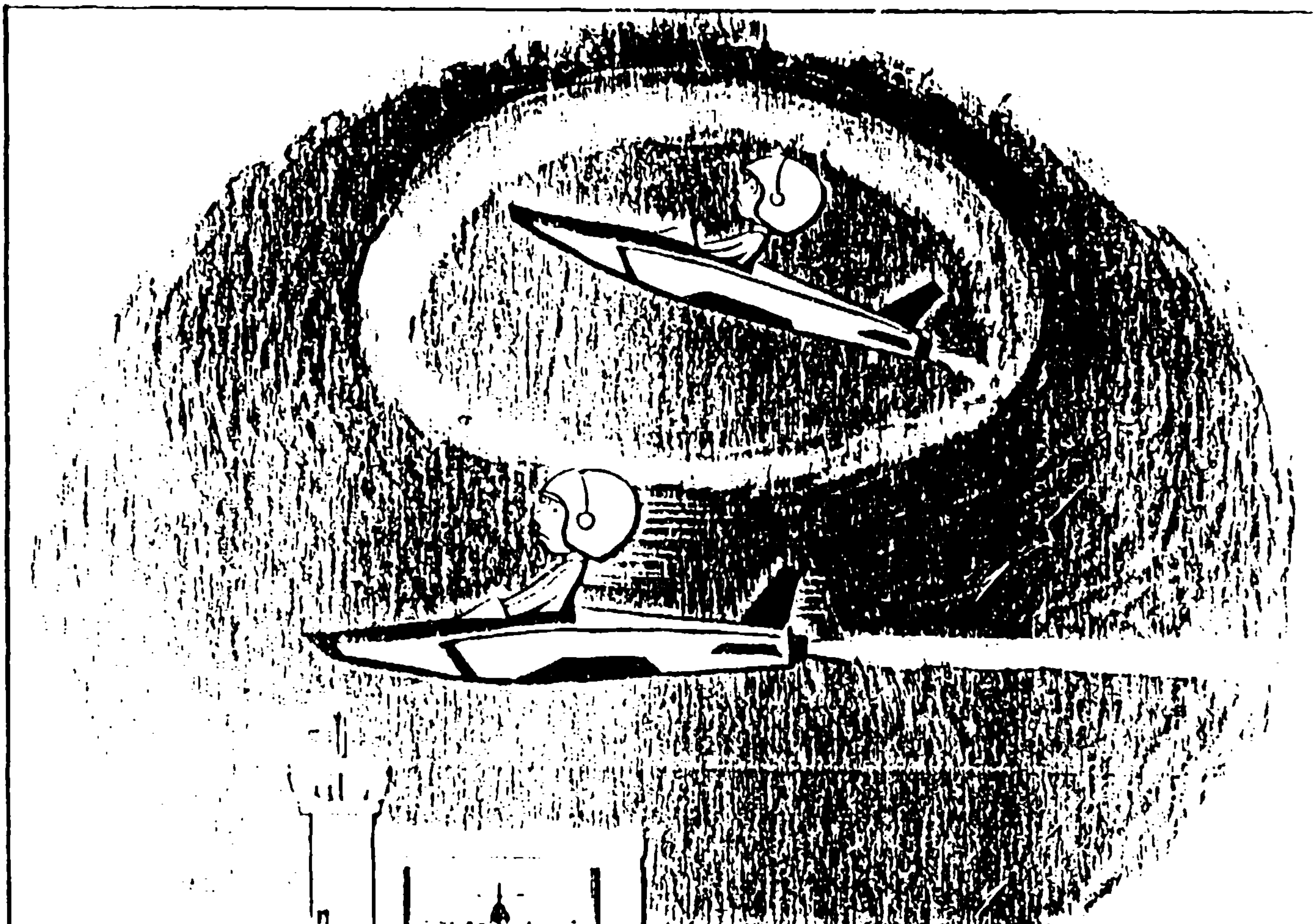


Figure 2.1 Force Vector Interaction in the Somatogravic Illusion (Buley and Spelina [1970])



When an aircraft accelerates forward, inertia causes the otolithic membrane in the otolith organs to move. This results in the sensation of climbing, and may cause the pilot to dive in an attempt to compensate for illusory change of attitude.

Figure 2.2 The Somatogravic Illusion Depicted
(Air Force Manual 51-37 [1986])

in Figures 2.1 and 2.2). Clark and Graybiel [1949] report that accelerative forces result in a change in both magnitude and direction of this resultant vector. The subject feels as if he is "pitching up," i.e., a sensation of backward tilt. Cramer and Wolfe [1970] describe this phenomenon as "a strong horizontal acceleration vector is added to the gravity vector, and the pilot is apt to operate upon the resultant of these two vectors" (p. 644).

It is important to understand the nature of the quantification of the somatogravic illusion for future reference in this study. Many resultant gravitoinertial force vectors can be duplicated in the nonflying environment by using linear acceleration to generate a number of body pitch positions. Since the force of gravity is constant, the gravitoinertial vector can, therefore, be accurately generated at many different controllable values. This concept leads to the formulation of a somatogravic illusion model which predicts at what pitch attitude any normal subject will perceive or believe themselves to be. So for any given linear acceleration and body tilt position there is a unique perceptual "feeling" of pitch across all subjects. For further coverage of this concept and specific model parameters, see Gillingham et. al.[1987] or Wolfe and Cramer [1970].

Dowd et. al.[1970] interviewed pilot trainees with respect to exposure to several spatially disorienting illusions. Here is a sample of what several trainees are quoted as saying about the somatogravic or posturogravic illusion:

> I got the feeling of rising. I did have it leveled, but I felt as if I were climbing. I have experienced a tendency to think the aircraft is climbing more than it should be on a takeoff at night (Dowd [1970], p. 548).

> I felt it; I also knew it wasn't real so I more or less ignored it. I have experienced it in flight - on takeoff especially at night immediately after liftoff when I lose sight of the horizon, compensating for it by referring to the instruments right off (Dowd [1970], p. 548).

Cohen, Crosbie, and Blackburn [1973] examine pilot performance after catapult launchings. This type of launching obviously exposes the pilot to tremendous amounts of linear acceleration, which produce both visual and postural illusions. The visual illusion or oculogravic illusion causes objects to appear to rise above their true positions, while the posturogravic or somatogravic illusion creates a sensation of backward tilt. As can easily be seen, these illusions complement each other. The pilot seemingly observes his instruments rising, while having a feeling that his aircraft is excessively nose-high.

In a related study, Cohen [1976] exposed subjects to simulated catapult launchings in a condition of total darkness and in a condition containing a spot of light projected externally in the mid-saggital plane of the subject. The measured somatogravic illusion tended to be smaller and to decay more rapidly during the spot of light condition. Figure 2.3 represents these results (Cohen [1976]). Cohen's inference was that the target spot of light somehow decreased the amount of somatogravic illusion. Probably, the spot of light acted like an external visual cue, thereby diminishing the launch-induced somatogravic illusion. In real-world circumstances, the lights of cockpit instruments can have an additive effect on the somatogravic illusion, by appearing to rise (oculogravic illusion) in conjunction with a pitching back "feeling."

As a final comment on the nature of the somatogravic illusion, Dowd [1974] references a study involving a spatial orientation trainer in which the largest performance errors occurred in the perception of pitch in the posturogravic or somatogravic illusion, so this is clearly a dangerous illusion, very worthy of study and quantification.

2.5 VESTIBULAR ROLE IN THE SOMATOGRAVIC ILLUSION

Graybiel [1956] discusses at length the otolith apparatus and its contribution to the somatogravic illusion. In the paired utricles of the labyrinths, the macular plates lie in the horizontal plane. The macula consists of a basilar structure containing sensory hair cells which extend upward into the gelatinous membrane

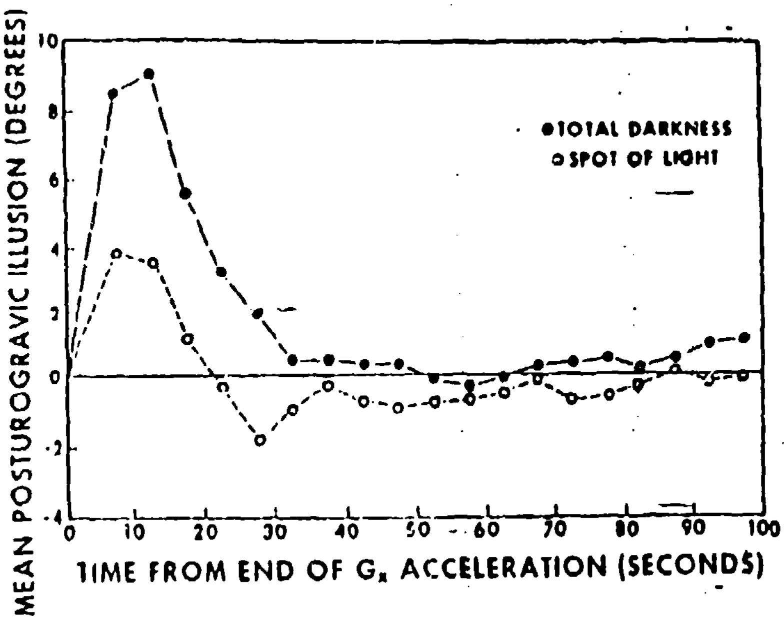


Figure 2.3 Mean Measured Posturogravic Illusions (Cohen [1976])

which contains the otoliths. The otoliths "sense" the force of gravity or any linear acceleration similar to gravity. A change in a force's direction, relative to the macula, causes a gliding of the otolithic membrane over the base thereby displacing the hair-like projections and leading to nerve-ending stimulation. Otolith organ study has been difficult due to the many other sensory inputs stimulated by gravity. Importantly, the otolith organs are not absolutely necessary to perception of human body position with respect to gravity.

As can be seen in Figure 2.4 (adapted from Benson [1965]), the utricle lies at the base of the semicircular canals. Figure 2.5, also adapted from Benson [1965], shows a very simplified depiction of a vertical section of the utricular macula. The hairs of the sensory cells enter into the canals of the gelatinous otolithic membrane. At an even smaller level, Figure 2.6 shows the individual sensory cells of the utricular macula.

Gillingham and Wolfe [1985] report that the physiological cause of the somatogravic illusion involves displaced otolithic membranes on their maculae, due to the inertial forces caused by the aircraft's acceleration. The inertial force resulting from the forward acceleration of takeoff displaces the otolithic membranes backward. The pilot "feels" pitched up and

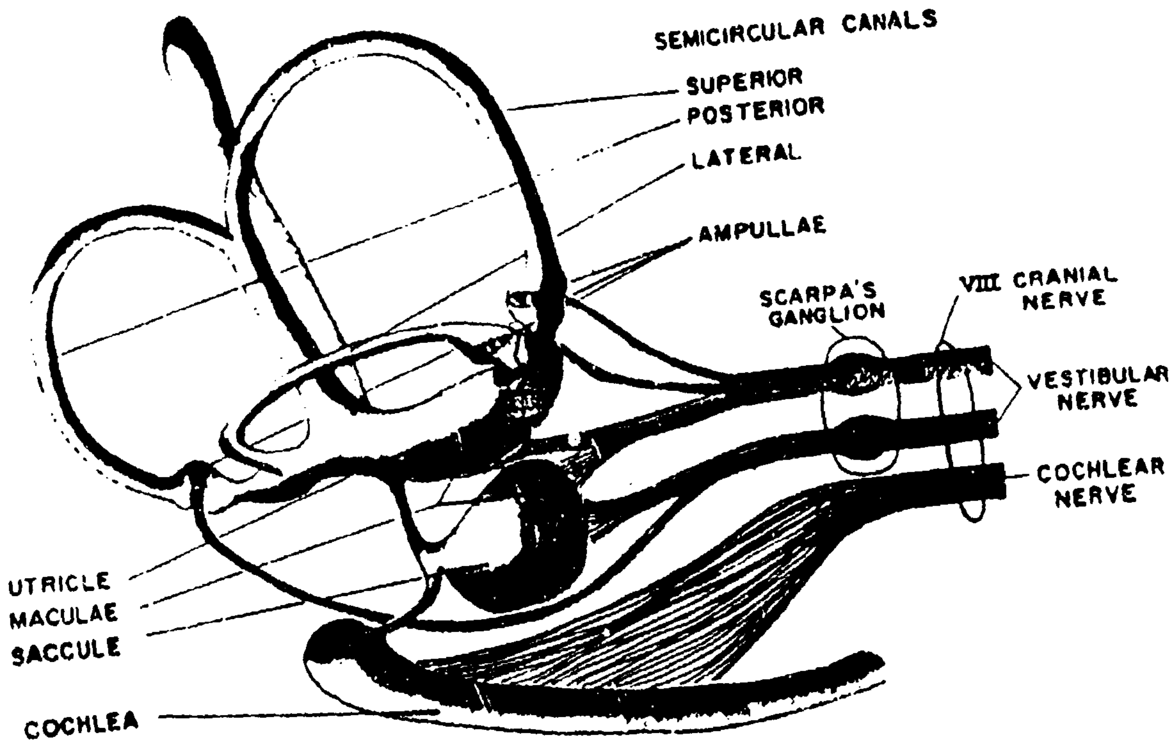


Figure 2.4 Vestibular Anatomy
(Benson [1965])

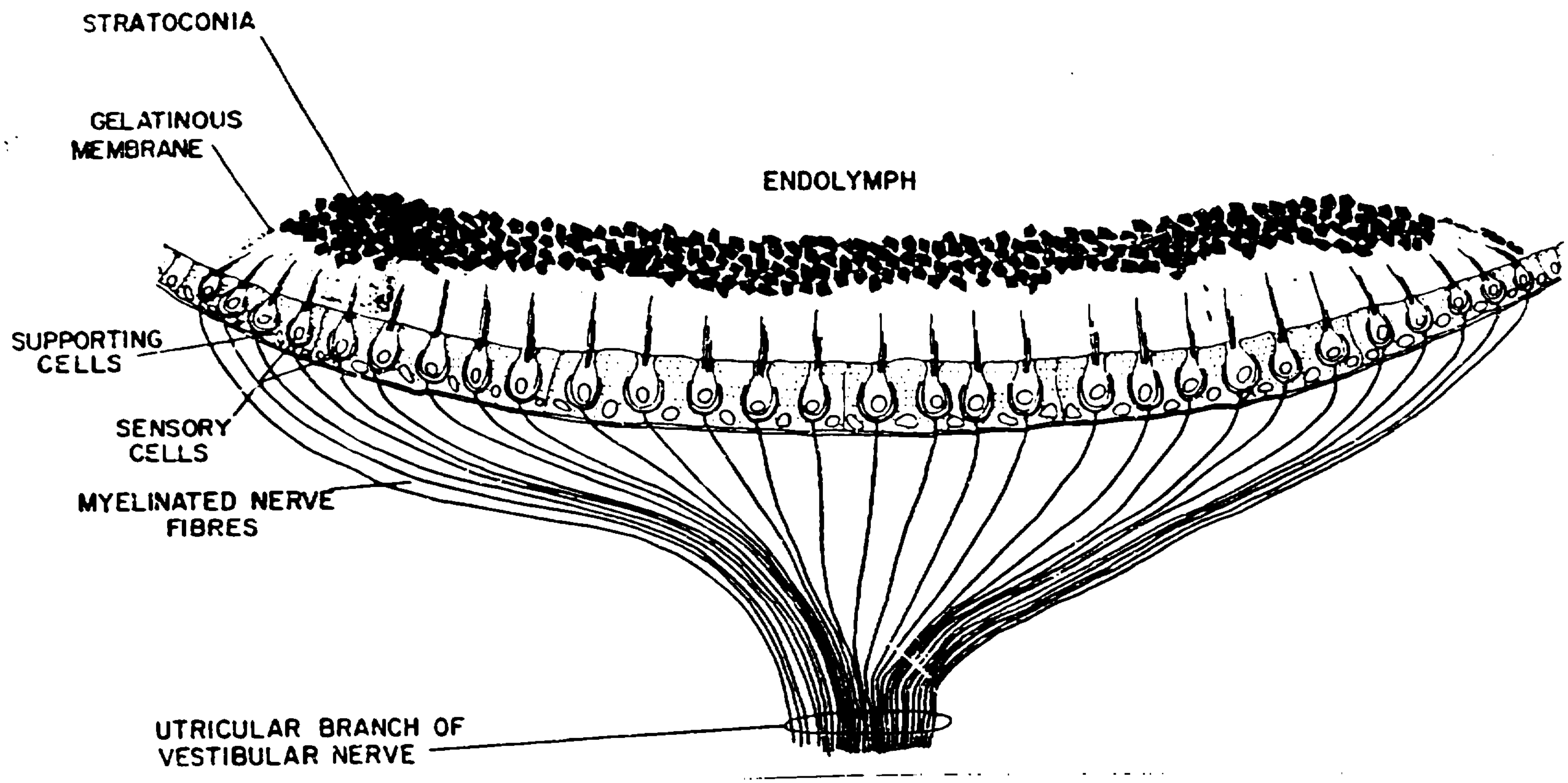


Figure 2.5 Utricular Macula Vertical Section (Benson [1965])

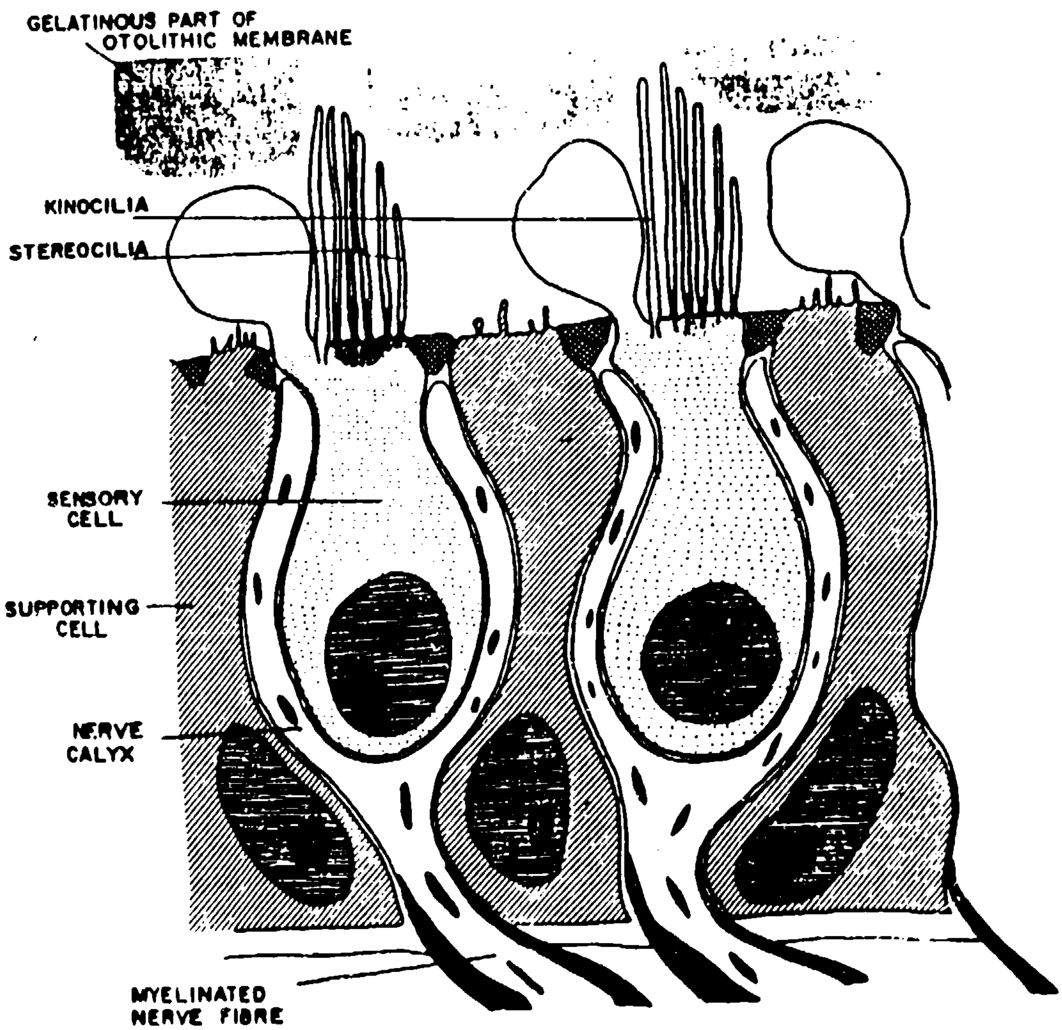


Figure 2.6 Simplified Sensory Cell Diagram
(Benson [1965])

information from other sensory modalities often reinforces this false sensation. The absence of distinct external visual orientation cues, or the presence of false visual cues reinforcing the vestibular disorientation only contribute to the illusion, as has been previously discussed.

In Figure 2.7 (adapted from Gillingham [1966]), three variations of otolith organ action are shown. When the head is tilted, the membrane moves, dragging the hair cells with it and stimulating a sensation of tilt which is transferred by way of the vestibular nerve to the brain. Figure 2.7A depicts the otolith organ in an upright position, Figure 2.7B shows the organ in an aft-tilt, and Figure 2.7C demonstrates a fore-tilt. Figure 2.8 (adapted from Gillingham and Wolfe [1986]) presents essentially the same information as Figure 2.7; however, both the slightly different format and the included explanation may be very useful. Additionally, Figure 2.9 (taken from Air Force Manual 51-37 [1986]) presents similar information, as well as a brief overview of the previously mentioned semicircular canals and their function.

In an effort to save at least some measure of respect for the vestibular and proprioceptive systems, Cramer and Wolfe [1970] explain that a spatial orientation trainer could permit the determination of the nature of vestibular and proprioceptive inputs that

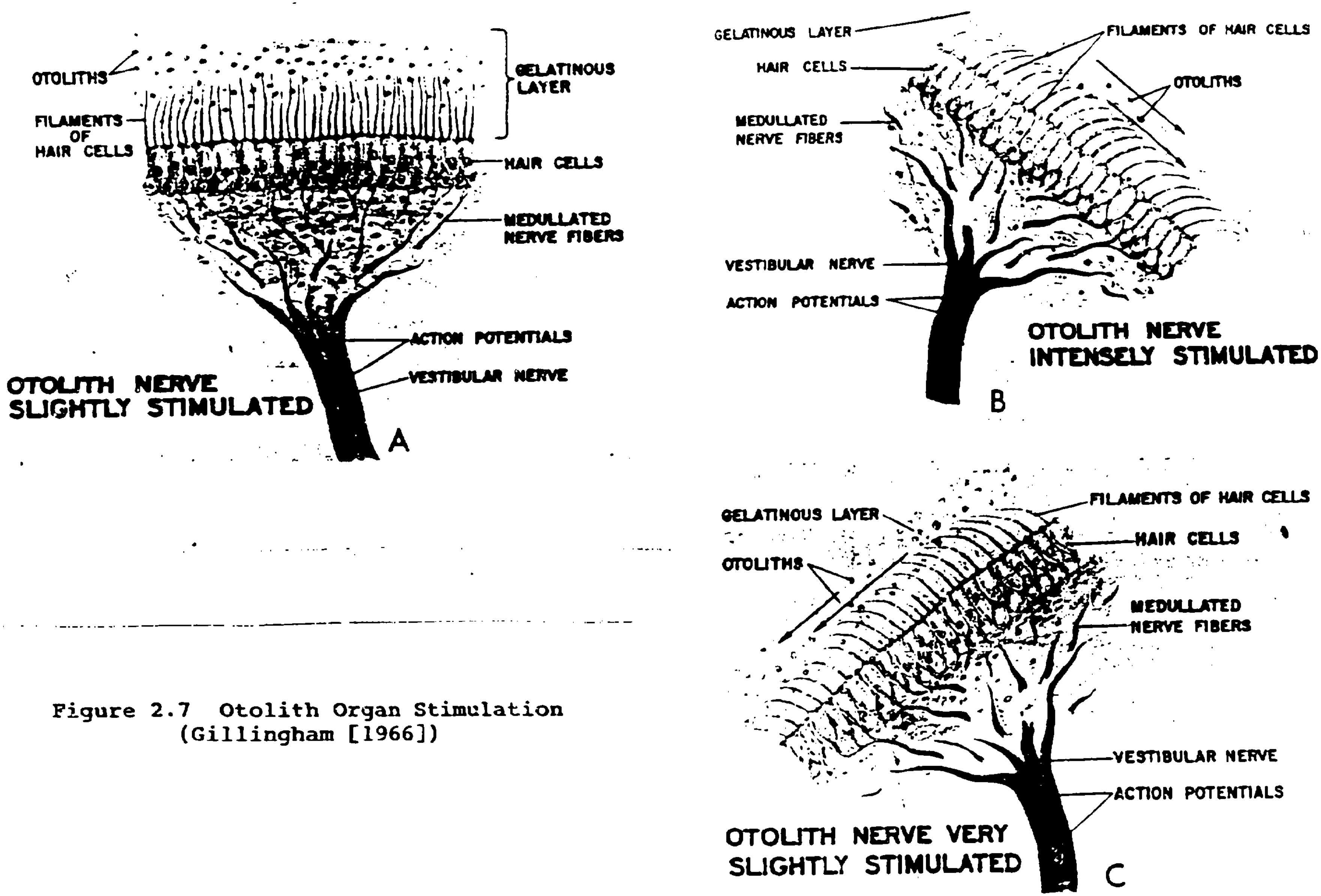
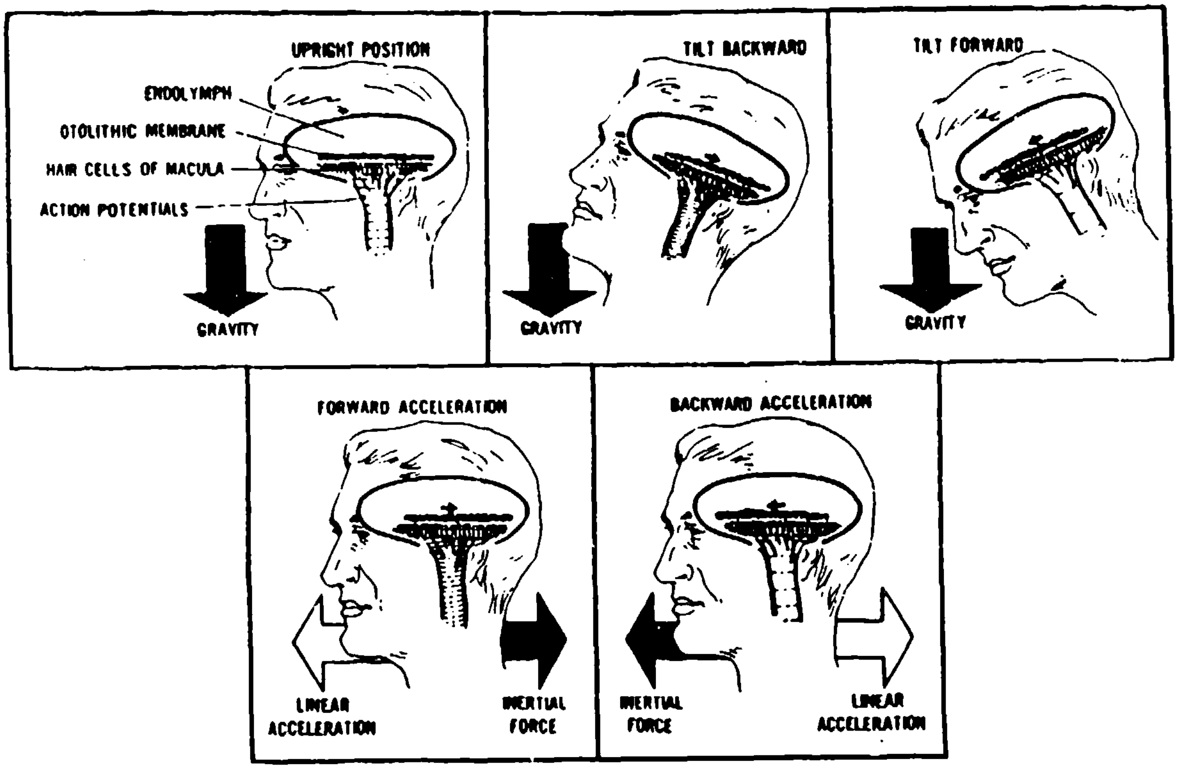


Figure 2.7 Otolith Organ Stimulation (Gillingham [1966])



Mechanism of action of an otolith organ. A change in direction of the force of gravity (above) or a linear acceleration (below) causes the otolithic membrane to shift its position with respect to its macula, thereby generating a new pattern of action potentials in the utricular or saccular nerve. Shifting of the otolithic membranes can elicit compensatory vestibulo-ocular reflexes as well as perceptual effects.

Figure 2.8 Otolith Organ Mechanism of Action (Gillingham and Wolfe [1986])

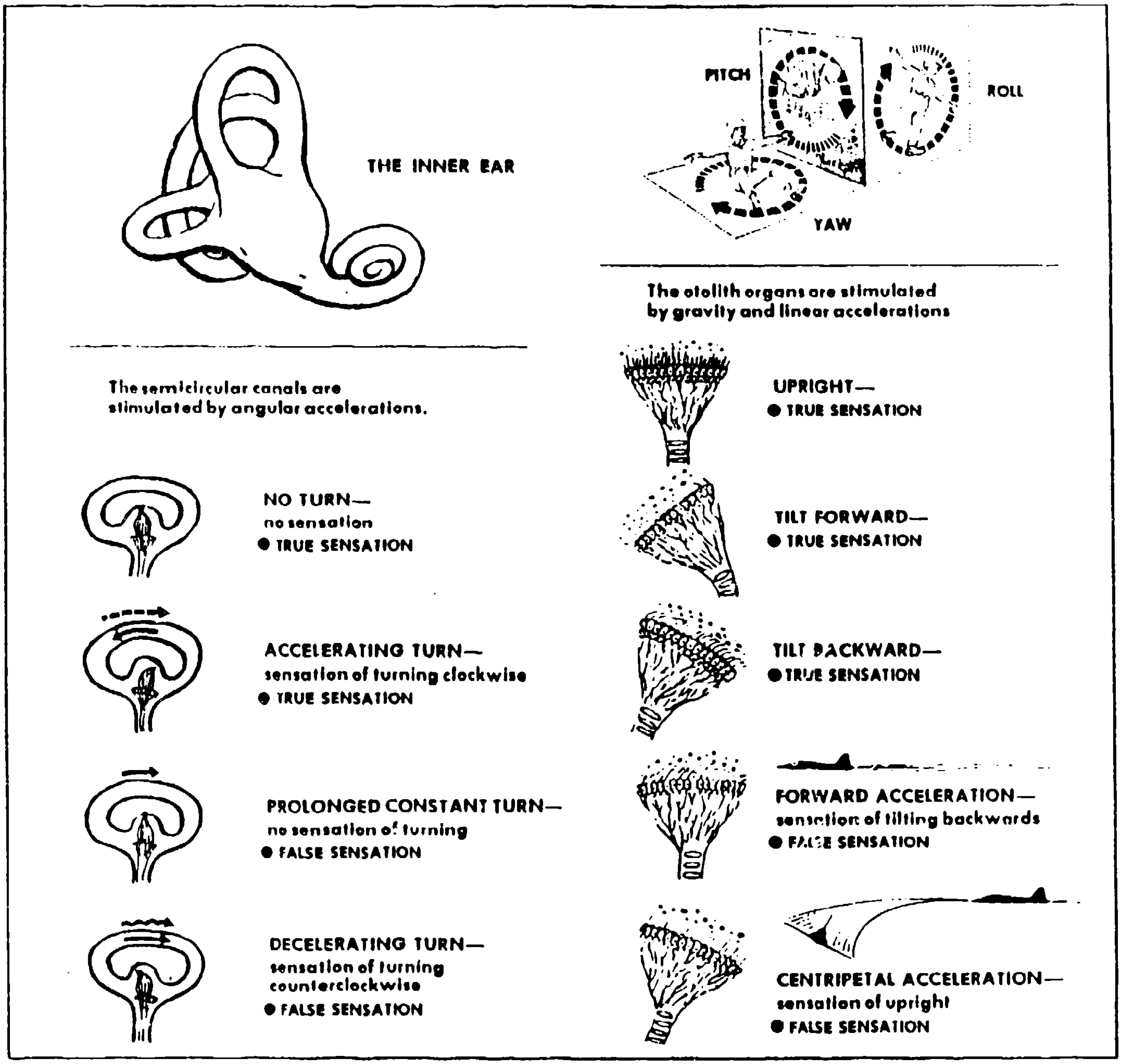


Figure 2.9 General Vestibular System Function (Air Force Manual 51-37 [1986])

pilots could use in operating aircraft, rather than "condemning" these systems simply because they induce illusions. The pilot could use all sensory inputs in an integrated, synthesized perceptual response instead of an "epistemologic struggle for supremacy between competing sensory modalities."

2.6 PURPOSES OF THE PRESENT STUDY

The purpose of the present study is to investigate pilot and nonpilot performance on both a canopy-mounted downpointer and a joystick-controlled attitude indicator. A difference between the devices in performance is expected, while no difference between pilot and nonpilot groups will confirm previous research by Wolfe and Cramer [1970].

Several other components of the background literature are included for the purposes of this study. First, Wolfe and Cramer [1970] report that both naive nonpilots and experienced pilots are equally susceptible to the illusion of pitch induced by centripetal acceleration. This fact indicates that no apparent sensory adaptation or habituation of otolithic information occurs from experience with flying or spatial disorientation training. The present study presents a unique opportunity to retest Wolfe and Cramer's [1970] conclusion of "no difference" between pilot and non-pilot performance. However, this "experience" factor will be further studied by the addition to the measurement environment of an apparatus with which pilots should be very familiar and nonpilots not familiar at all (see Chapter III).

Secondly, an illuminated cockpit, as is the case in one of the present study's conditions (see Chapter III), does not enhance or attenuate the illusion as compared with a total darkness condition (Cramer and Wolfe [1970]). This finding suggests that the primary sensory input is from otolithic stimulation, and as Cramer and Wolfe [1970] further express, proprioceptive input appears to play a small role in perception when normal otolith function is present.

Another factor of importance is McNaughton's [1985] contention that, under conditions of poor visibility, pilots dwell on the attitude indicator up to 75% of the time. This could have implications for the subject's ability to use various instrumentation, as one of the present study's conditions requires visual interpretation and fixation on an attitude indicator.

The USAFSAM's active research program in spatial disorientation is currently examining the effects of a number of different experimental variables on the ability of subjects to experience the potentially devastating effects of the somatogravic illusion and others. An accurate and valid means of recording the magnitude and direction of the somatogravic and other illusions is necessary for such research. In this regard, USAFSAM is interested in the results of an evaluation of two different subject-controlled attitude indicators. One device is a simple downpointer, while the other is a joystick-controlled attitude indicator.

The description of these attitude indicators is included in Chapter III. Generally speaking, it was predicted that one device would be better than the other at quantifying the somatogravic illusion, although it was unclear which would prevail. The accuracy of the devices was measured in degrees difference from the predicted value. One device, the joystick-controller, provides visual feedback, while the downpointer does not. The null hypothesis indicates equality of the devices, while the rejection of the null hypothesis could indicate that a) the joystick-controlled attitude indicator is less accurate due to the requirement for more mental processing (to translate position into a reading on the attitude indicator) or due to visual interference with the vestibular illusion; or b) the attitude indicator is more accurate due to visual display feedback.

CHAPTER III

METHODOLOGY

3.1 SUBJECTS

Sixteen USAF personnel, all testing normal on an 11-part vestibular screening exam, volunteered to participate as subjects. Eight of the personnel were experienced military or civilian pilots, while the other eight were naive nonpilots. The nonpilot subjects had no previous aircraft piloting experience. Subjects were encouraged not to eat within three to four hours of their scheduled participation. This precaution was taken in order to avoid any serious symptoms of motion sickness.

3.2 APPARATUS

Testing was conducted in the USAFSAM Vertifuge (built by the EMRO Corporation). It can best be described as a small centrifuge that can be adjusted during "flight" along the pitch and roll axes to a maximum of 30 degrees in either direction. It can rotate at a maximum of 25 rpm and expose a subject to a maximum of 1.6 G. The device is primarily used to train and expose pilots to various spatially disorienting illusions and sensations which can occur during flight, as well as to conduct research upon the same parameters. The compartment or cockpit in which subjects sit is covered by a blacked-out canopy that prevents all light from entering the compartment. The Vertifuge generates the somatogravic illusion through centrifugal force pushing outward against the subject, as he/she faces the axis of rotation (inward). This centrifugal force simulates an inertial force acting parallel to the moment arm of the Vertifuge.

The first apparatus tested, the canopy-mounted downpointer, is the current method used for subjects to indicate their subjective pitch and bank attitudes or positions. In complete darkness, subjects move the downpointer to the direction that they perceive to be the direction of the gravity vector. The deviation of the subject's estimate from the true gravity vector can be measured quite easily and is the metric used in quantifying spatial disorientation illusions.

Figure 3.1 (Gillingham et. al.[1987]) shows the downpointer in its mounted position; above, centered, and forward of the subject's seated position. Figure 3.1 also shows the centrifugal force vector generated by rotation of the Vertifuge, the gravity force vector, and the resultant gravitoinertial force vector which is the combination of the previous two. It is this vector that the pilot confuses with the gravitational vector, thereby inducing the somatogravic illusion. The general shape of the Vertifuge's compartment and the sitting position of the subject is also shown in Figure 3.1.

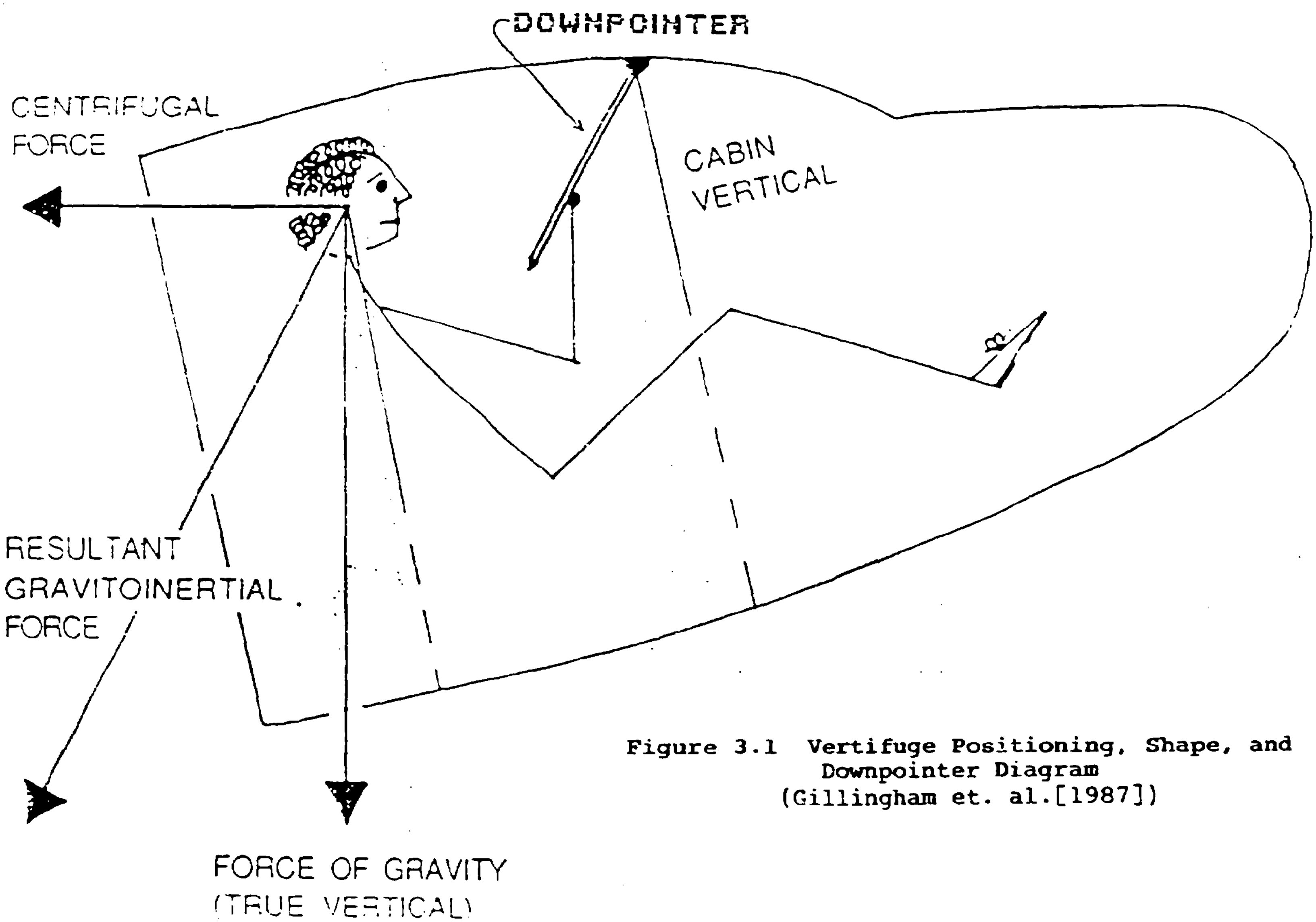


Figure 3.1 **Vertifuge Positioning, Shape, and Downpointer Diagram (Gillingham et. al.[1987])**

An experimental device, also designed to quantify spatial disorientation, has recently been developed and can easily be installed into the Vertifuge. It can best be described as a remote-control inside-out aircraft attitude indicator, actuated by a joystick. According to McCormick and Sanders [1982], inside-out indicators represent the aircraft as a fixed object, with the horizon moving with respect to the aircraft. Straight-and-level flight is indicated by the even overlap of wings and horizon. The device was developed by Dr. Nita L. Lewis in order to better approximate a true cockpit environment. Dr. Lewis' contention was that the downpointer is unrealistic and provides the subject with proprioceptive cues (allowing the weight of the arm to influence measurement) that would not normally be relied on in the flying environment. The attitude indicator inhibits, and may even prevent, this type of "cheating" or unrealistic cue. The device consists of a small hand-actuated joystick resting on the subject's lap, which remotely controls an attitude gyro-ball indicator, mounted on the center of the cockpit instrument panel. Any movement of the joystick is reflected in a corresponding movement of the display indicator. This apparatus, unlike a true aircraft indicator, represents the subject's perceived attitude rather than the true aircraft attitude. An important difference between this device and the downpointer is that rather than performing observations in total darkness, the attitude indicator is backlit so that the device may be seen. In other words, the instrument panel and cockpit are lit during attitude indicator trials and completely dark during downpointer trials.

The attitude indicator used in this device is similar to that found in F-4 aircraft. It distinguishes sky from surface through a gray-to-black color scheme and depicts the horizon as a dashed line. The gyro-ball moves in both the pitch and roll axes, with the pitch axis being labeled in 5-degree increments up to 90 degrees in either direction. Figure 3.2 is a picture of the face of the attitude indicator ball. The upper portion of the gyro-ball, labeled "CLIMB," moves downward past the simulated, center-fixed wings to indicate a pitched-up position, while the lower portion, labelled "DIVE," moves up to indicate a pitched-down position.

The joystick controller (Futaba Corporation), which actuates the attitude indicator in pitch and roll, is similar to those used in flight control of model airplanes. Figure 3.3 (Futaba Operation Manual [No Date]) depicts the joystick-controller.

All Vertifuge operations and data output are controlled from an operator's console located adjacent to it. Important data parameters which were monitored and recorded throughout the course of the present study

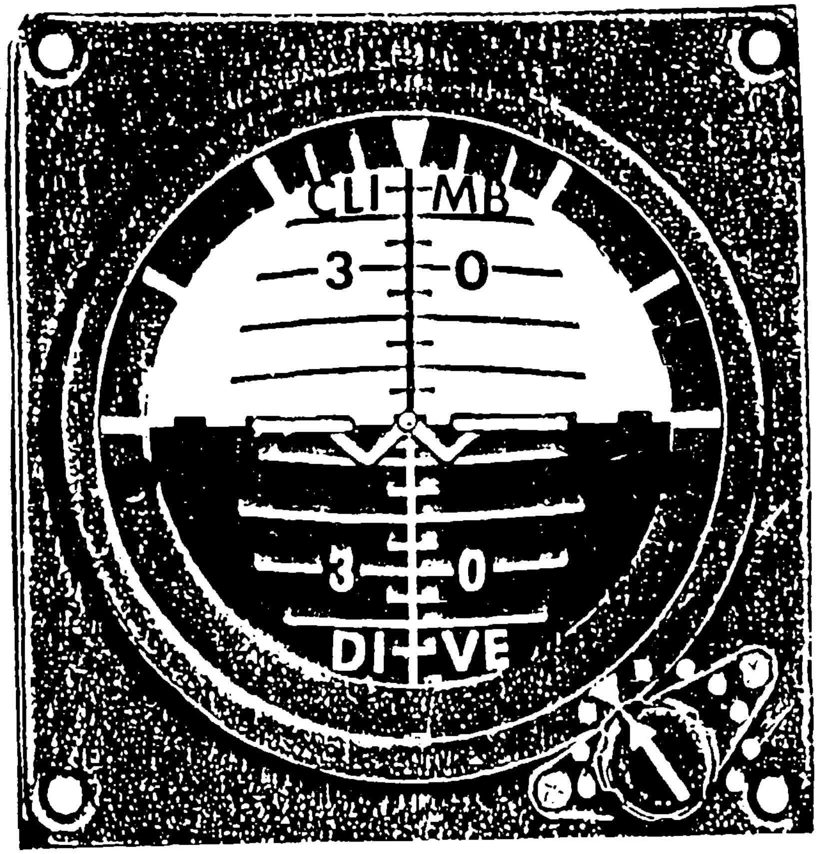


Figure 3.2 Attitude Indicator Front Panel
(Air Force Instrument Flight Center Photo)

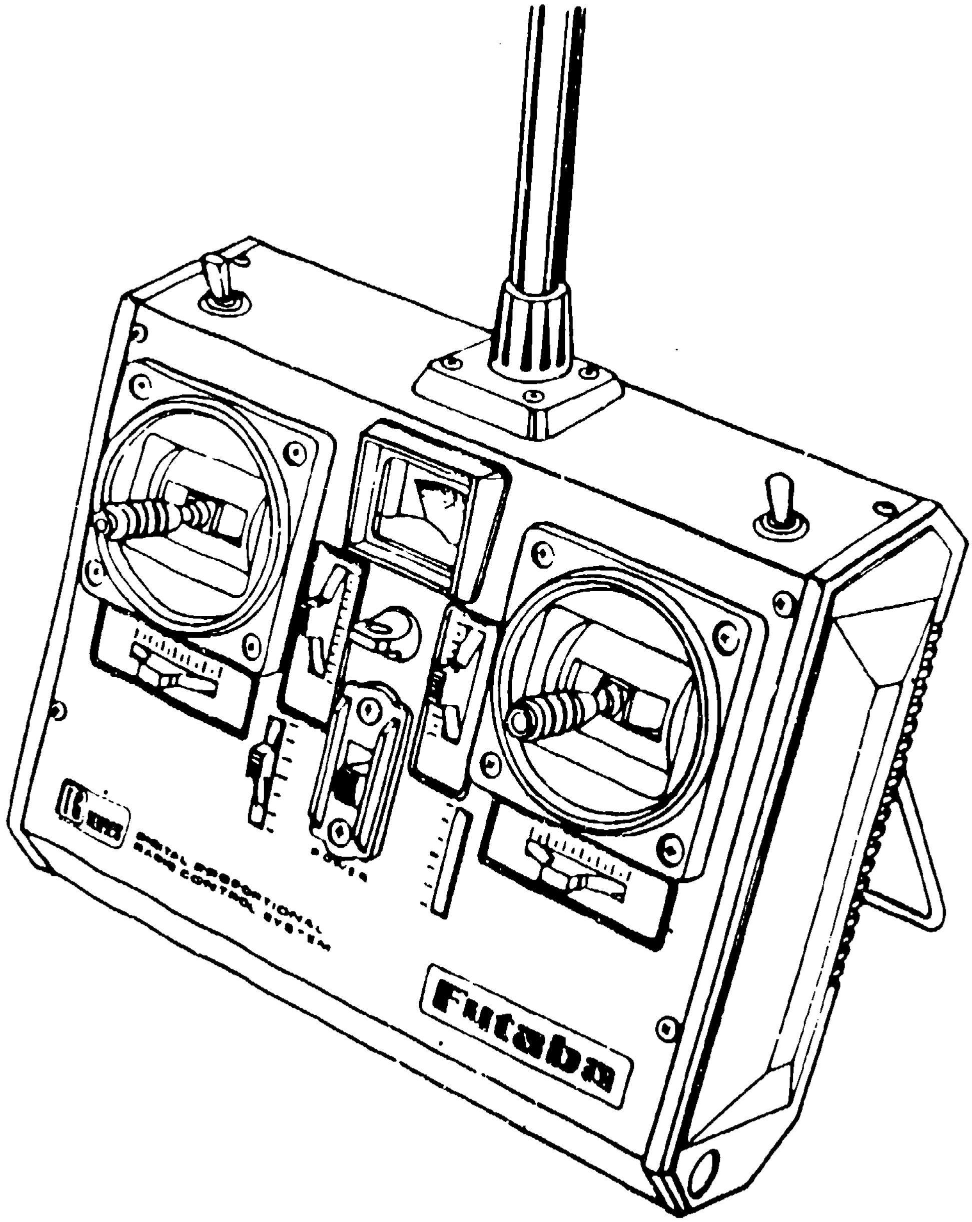


Figure 3.3 Futaba Joystick-Controller
(Futaba Operations Manual)

included the speed of rotation of the Vertifuge (RPM), the pitch angle of the cockpit (-30 to +30 degrees), and the readout of the subject's perceived pitch angle as indicated by the two devices (in degrees).

3.3 DESIGN

For practical considerations, each subject was exposed to both the downpointer and the joystick-controller in a counterbalanced design. The scarcity of qualified subjects, time constraints, and Vertifuge availability made it less desirable to design a study of two randomized groups, each being exposed to only one of the devices. Instead, each subject experienced both devices in two different sessions. The order of presentation of the devices is alternated for each subject, partially controlling for any learning effect from one apparatus to the other.

Campbell and Stanley [1963] define a counterbalanced or cross-over design as that design "in which experimental control is achieved or precision enhanced by entering all respondents (or settings) into all treatments." In other words, all the subjects will use both the downpointer and the attitude indicator in different trials. Graphically, the design is presented in Table 3.1 (Campbell and Stanley [1963]). The eight pilots involved in the study were randomly divided into two separate groups, Pilots1 and Pilots2. Pilots1 used

GROUP	DOWNPOINTER	ATTITUDE INDICATOR
Pilots1	s1,O	s2,O
Pilots2	s2,O	s1,O
Nonpilots1	s1,O	s2,O
Nonpilots2	s2,O	s1,O

Table 3.1 Counterbalanced Design

the downpointer in session #1 (s1) and the attitude indicator in session #2 (s2), while Pilots2 experienced the attitude indicator in s1 and the downpointer in s2. The same technique is applied to nonpilots. The "O's" in Table 3.1 represent "observations" made during the trials.

3.4 PROCEDURE

Prior to participation, each subject was asked to read and sign a consent form which explained the general nature of the study and the types of sensations he or she might experience (See Appendix A). Additionally, each subject was administered a preliminary vestibular screening in order to eliminate any subjects with abnormal or dysfunctioning vestibular systems. The screening consisted of a battery of 11 motor skill and sensory tests in which vestibular abnormalities would be readily apparent (See Appendix B). Prior to the experiment, a measurement was taken of each subject, in the Vertifuge seat, for the purpose of identifying the required rotational velocity necessary to generate the gravitoinertial vectors corresponding to particular induced pitch angles. Although the computations are rather complex, the measurement was easy and was essentially dependent upon the subject's sitting height.

Prior to each session, subjects were given a brief training period in which to familiarize themselves with the operation of the given device and to experience several randomly selected pitch attitudes.

Upon training completion, each subject was exposed to resultant gravitoinertial forces (0 to 50 degrees) and cabin pitch positions (-30 to +30 degrees) in 10 degree increments. For each subject, the presentation order of the six gravitoinertial forces was assigned randomly, as was the presentation of the seven cabin pitch values for a given force level. A total of 42 (6 x 7) different combinations of force direction and pitch angle were thereby achieved. Presentation order for the second session was exactly opposite that faced in the first session.

After exposure to a position, it was necessary to allow the subject to "acclimate" to that position, permitting the possibly uncomfortable feeling of angular acceleration to subside. When the subject felt stabilized, he/she was asked to identify their perceived position in space (Gillingham, Shochat, and Fischer [1987]). With the downpointer, the subject attempted to direct it towards the subjective gravitational vertical or perceived "straight down"; and with the joystick, the subject attempted to represent his or her impression of the compartment's attitude with respect to the horizon.

Data pertaining to position and subject response (including deviations from predicted values) was manually recorded from the operator's console (See Appendix C).

CHAPTER IV

EXPERIMENTAL RESULTS

4.1 BACKGROUND

Statistical evaluation of the data was accomplished using both descriptive and inferential means, including a simple proportions test and an analysis of variance (ANOVA). The SAS User's Guide was used in the formulation of several analysis programs. It is important to note that the primary measure used in all analyses was the deviation of the subject's perceived pitch from the expected or predicted value.

As has been discussed, each subject performed 42 different measurements in two separate sessions for a total of 84 observations per subject (over 16 subjects, are a total of 1344 observations). There were no missing data. Data were formatted by subject name and include the following parameters: pitch angle of the compartment (ANGLE), g-direction (FORCE), rotational velocity (RPM), observed value (ACTUAL), and predicted value (PRED). By subtracting PRED from ACTUAL (ACTUAL - PRED), a value termed DIF was created. This DIF represents the deviation of the observed from the predicted value.

4.2 DESCRIPTIVE STATISTICS

An initial way to look at the data is to summarize the relevant descriptive statistics about each of the devices. Although this study is not primarily concerned with the differences in performance between pilots and nonpilots, these data are also included for informational and further research purposes.

Statistic	DP	AI
Mean	-4.23	-16.92
Std Dev	9.49	13.83
Variance	90.06	191.30
Max Positive Deviation	30.2	47.7
Max Negative Deviation	-43.2	-51.8
Range	73.4	99.5
Median	-3.9	-16.4
Mode	-2.8	-19.7
Interquartile Range	11.53	20.05

Table 4.1 DIF values for the Downpointer (DP) and Attitude Indicator (AI) in degrees.

As can be seen in Table 4.1, the downpointer device performed much better than the attitude indicator in estimating the predicted pitch angle of the gravitoinertial force. The mean deviation from the predicted is less for the downpointer, and the standard deviation is less as well. The range of deviations for the downpointer is roughly only 74% as large as the range of deviations for the attitude indicator. On both devices, the median and the mode closely approximate the mean; therefore, one can infer a rough normality in deviations and establish several good measures of central tendency.

Table 4.2 has been constructed to show the descriptive statistics for pilot and nonpilot groups.

	DP		AI	
Statistic	P	NP	P	NP
Mean	-4.97	-3.49	-17.33	-16.50
Std Dev	9.30	9.64	15.30	12.19
Variance	86.43	92.86	234.22	148.61
Max Deviation	19.3	30.2	47.7	12.6
Min Deviation	-32.9	-43.2	-51.8	-51.7
Range	52.2	73.4	99.5	64.3
Median	-4.35	-3.6	-19.25	-15.35
Mode	-5.5	-2.8	-13.9	-19.7
Interquartile Range	12.55	10.8	23.35	17.1

<u>Table</u> <u>4.2</u> Descriptive statistics of DIF by Pilot (P) vs. Non-pilot (NP).

The results from these subsets of the data are quite similar to the results of the overall device comparison. There are several values worth noting. The variance of observations found in nonpilots on the attitude indicator is less than the variance found for pilot observations on the same device. Additionally, there are several anomalies found concerning the various range measures.

Another way to define the value of the deviation

DIF is to consider all deviations as absolute, rather than signed, under-and over-estimations (Table 4.3). Although this conversion renders several statistical inference techniques unusable, it does provide an interesting analysis that further enhances the downpointer's advantage over the attitude indicator.

Statistic	DP	AI
Mean	8.02	18.27
Std Dev	6.60	11.99
Variance	43.58	143.71

Table 4.3 Descriptive statistics considering DIF as an absolute value.

Here again one may observe some striking results: the mean, standard deviation, and variance of the downpointer is much lower than that of the attitude indicator.

In order to consider the different predicted values which exist for each combination setting of the compartment angle and RPM, Table 4.4 is provided to show the mean and standard deviation of each device at each predicted value (-30 to +80). Table 4.4 clearly shows how the attitude indicator underestimates the predicted positive-pitch values. Although it does seem to more accurately reflect the negative predicted values, the standard deviations are very large and the number of observations are small, decreasing any potential

		DP		AI	
PV	#	Mean	StDev	Mean	StDev
-30	32	-22.14	8.75	-31.38	10.13
-20	64	-16.23	5.24	-22.12	10.37
-10	96	-8.68	6.33	-14.09	6.90
0	128	-0.51	4.44	-7.42	4.53
+10	160	8.56	6.17	0.05	2.31
+20	192	15.73	4.47	5.28	5.35
+30	192	24.07	4.78	9.23	4.09
+40	160	32.92	7.04	13.57	6.33
+50	128	41.46	9.65	23.75	10.29
+60	96	51.13	10.21	34.15	13.94
+70	64	59.43	12.51	40.46	14.22
+80	32	70.83	9.19	53.49	22.20

Table 4.4 Means and Standard Deviations of DIF at each predicted value (PV) level. "#" represents the total number of observations at that PV.

statistical significance. Figure 4.1 plots the means and standard deviations from Table 4.4, and Figures 4.2 and 4.3 show similar plots for pilots (Figure 4.2) and nonpilots (Figure 4.3). All graphs plot actual vs. predicted values.

Before applying any inferential statistics on the existing data, a simple proportions test was conducted. In this analysis, the value DIF (deviation) was compared against several criterion values. Proportions of observations that fall outside of the criterion values

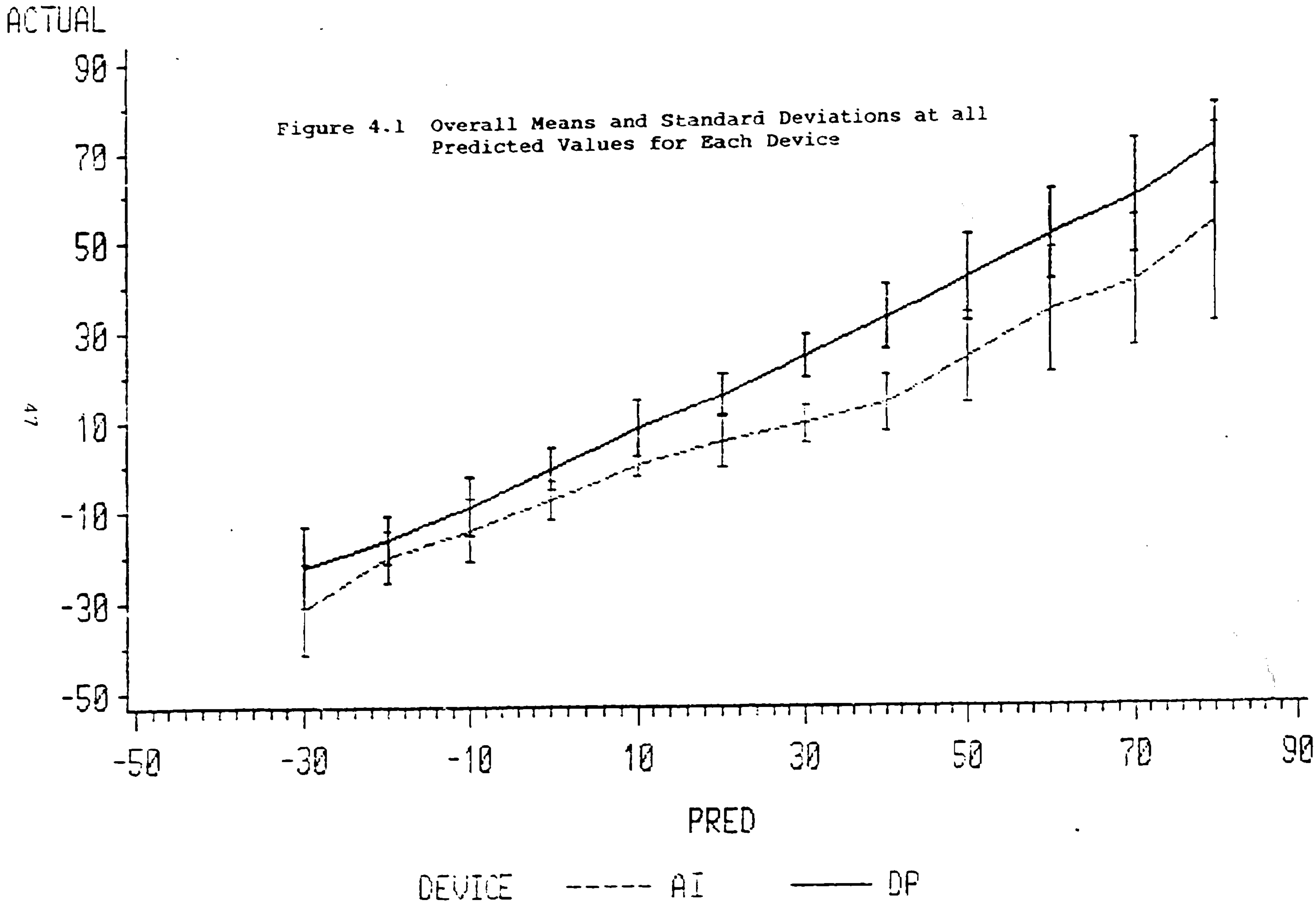


Figure 4.1 Overall Means and Standard Deviations at all Predicted Values for Each Device

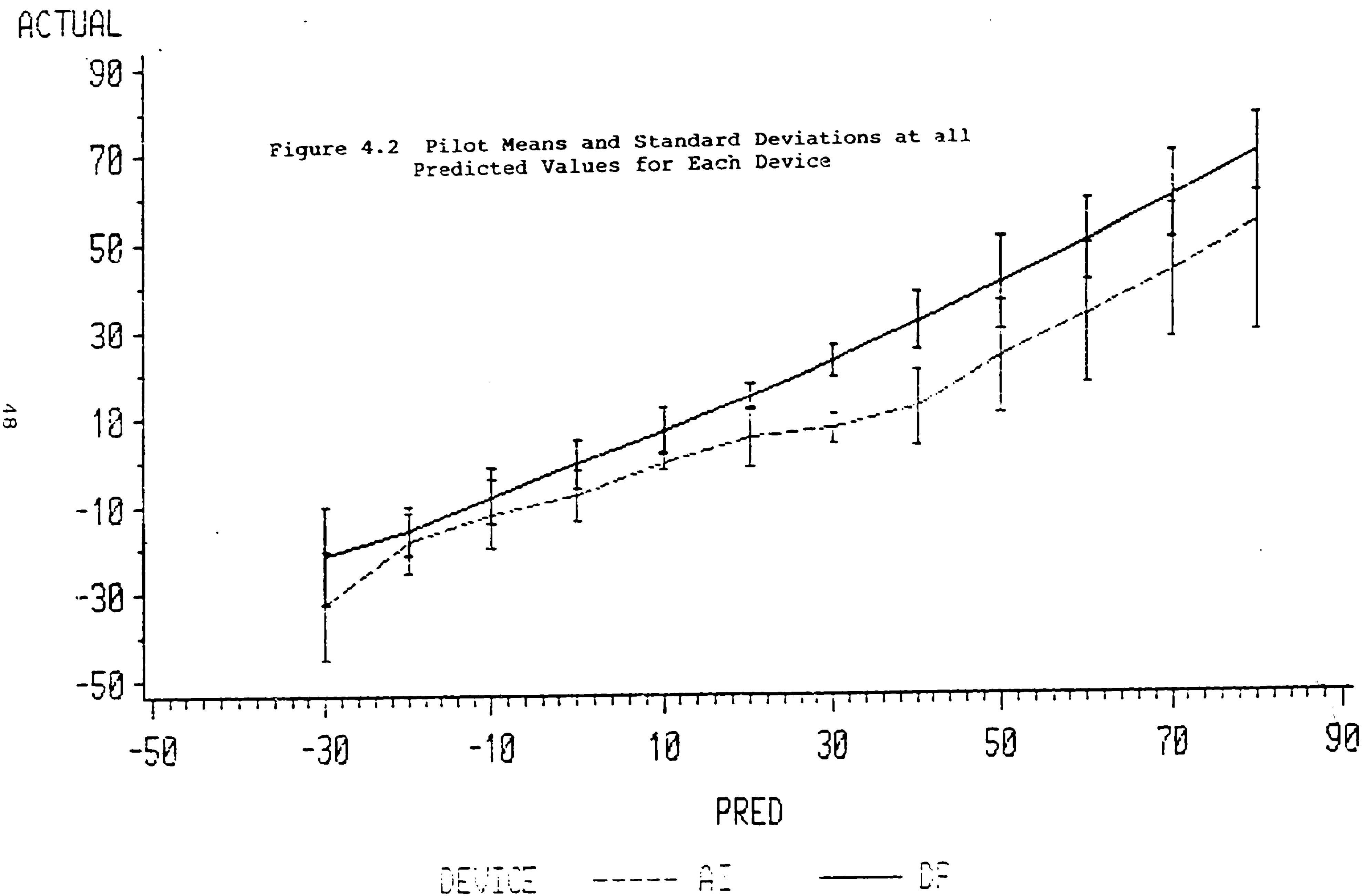
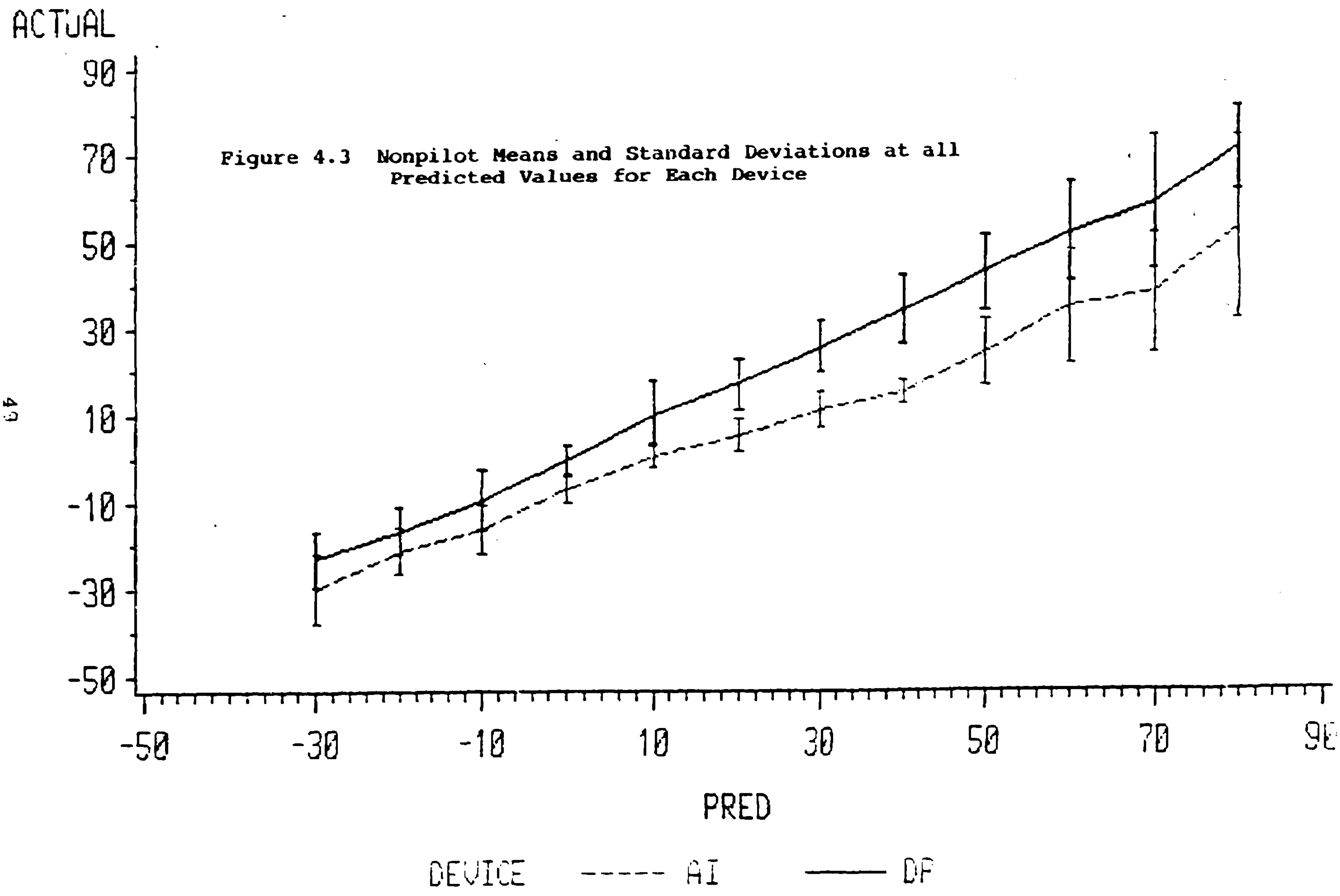


Figure 4.2 Pilot Means and Standard Deviations at all Predicted Values for Each Device

Figure 4.3 Nonpilot Means and Standard Deviations at all Predicted Values for Each Device



were compared between the two devices. The criterion values selected were: greater than 5 degrees deviation (GT5), greater than 10 degrees deviation (GT10), and greater than 15 degrees deviation (GT15). Deviations were considered as absolute values and results are contained in Table 4.5.

	PERCENT OF OBSERVATIONS OUTSIDE CRITERIONS	
CRITERION	DP	AI
GT5	61%	84%
GT10	29%	71%
GT15	15%	54%

Table 4.5 Percentage of observations falling outside criterion ranges of greater than 5, 10, and 15 degrees.

Obviously, the downpointer was more accurate at all three criterion levels, having the smaller percentage of out of boundary observations. The most glaring example of this was found at the GT15 deviation level; while only 15% of the downpointer observations lay outside 15 degrees in either direction from the predicted value, over half (54%) of the attitude indicator observations were more than 15 degrees away from the predicted.

Another way to describe the existing data was to plot the regression lines of each device on a graph of actual vs. predicted values. The slope and intercept of each device's function could then be compared to the other and also to the given predicted line. This predicted line possessed an intercept of zero and a slope of 1.0. Figures 4.4, 4.5, and 4.6 represent the regression line plots for the of the actual vs. predicted means for the two devices averaged across all subjects (Figure 4.4), and two other plots representing actual vs. predicted pitch angles for each device within the pilot (Graph 4.5) and nonpilot (Graph 4.6) subgroups. Upon visual inspection, no apparent difference among the three graphs can be observed. Their regression parameters are listed in Table 4.6, which shows the intercept, slope, and correlation of the four lines representing each group on each device.

	DP		AI	
Statistic	P	NP	P	NP
Intercept	-.760	.174	-9.200	-8.395
Slope	.832	.854	.675	.676
Correlation	.9369	.9308	.8140	.8985

Table 4.6 Regression line intercept, slope, and correlation for pilots and nonpilots on each device.

Table 4.6 shows quite well the relationships between the various intercepts and slopes of the regression lines. Most importantly, it shows similarity between pilots and nonpilots on both devices, and the major differences which exist between the devices. The regression line that represents both pilot and non-pilot performance on the downpointer has an intercept of

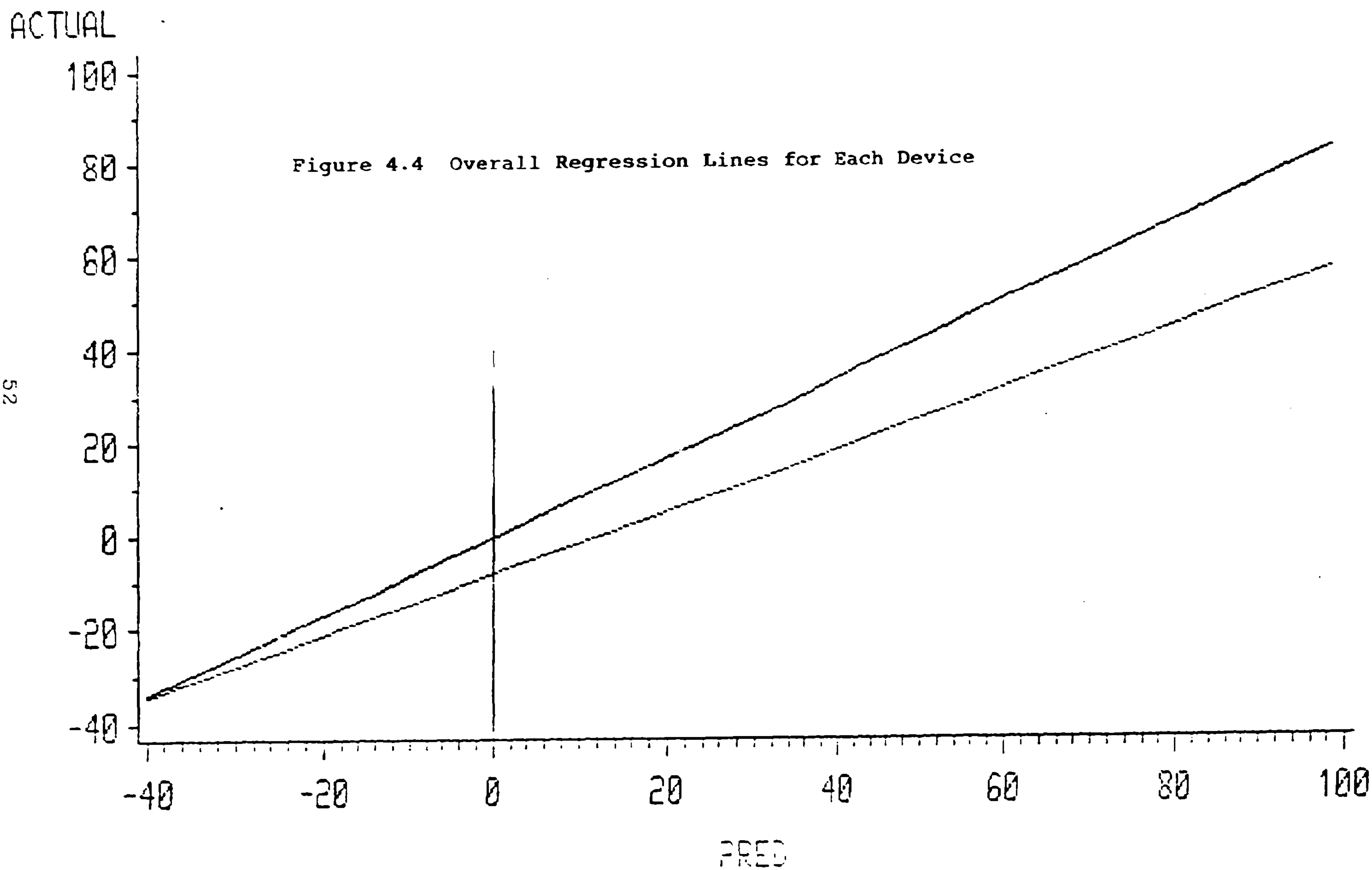


Figure 4.4 Overall Regression Lines for Each Device

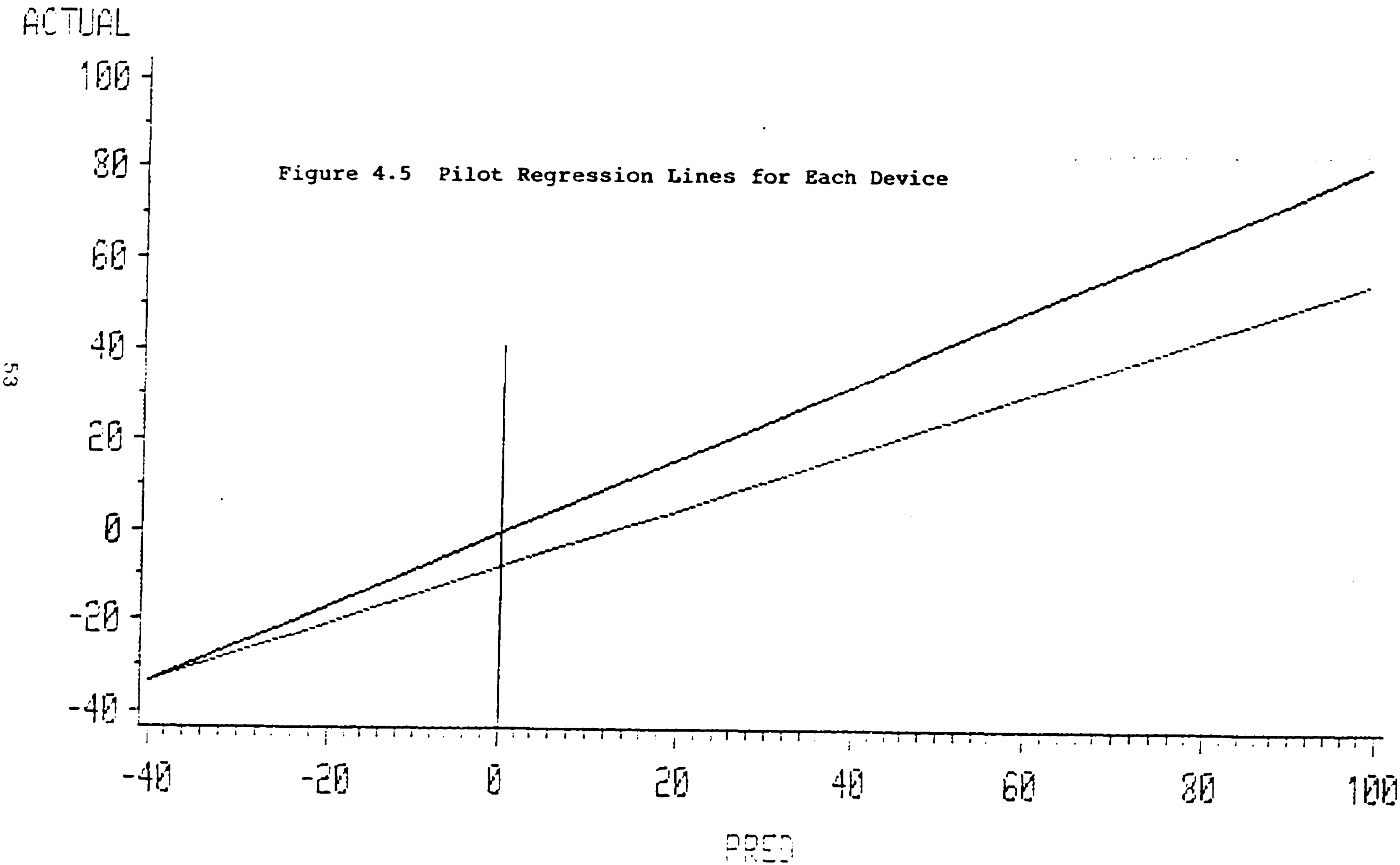


Figure 4.5 Pilot Regression Lines for Each Device

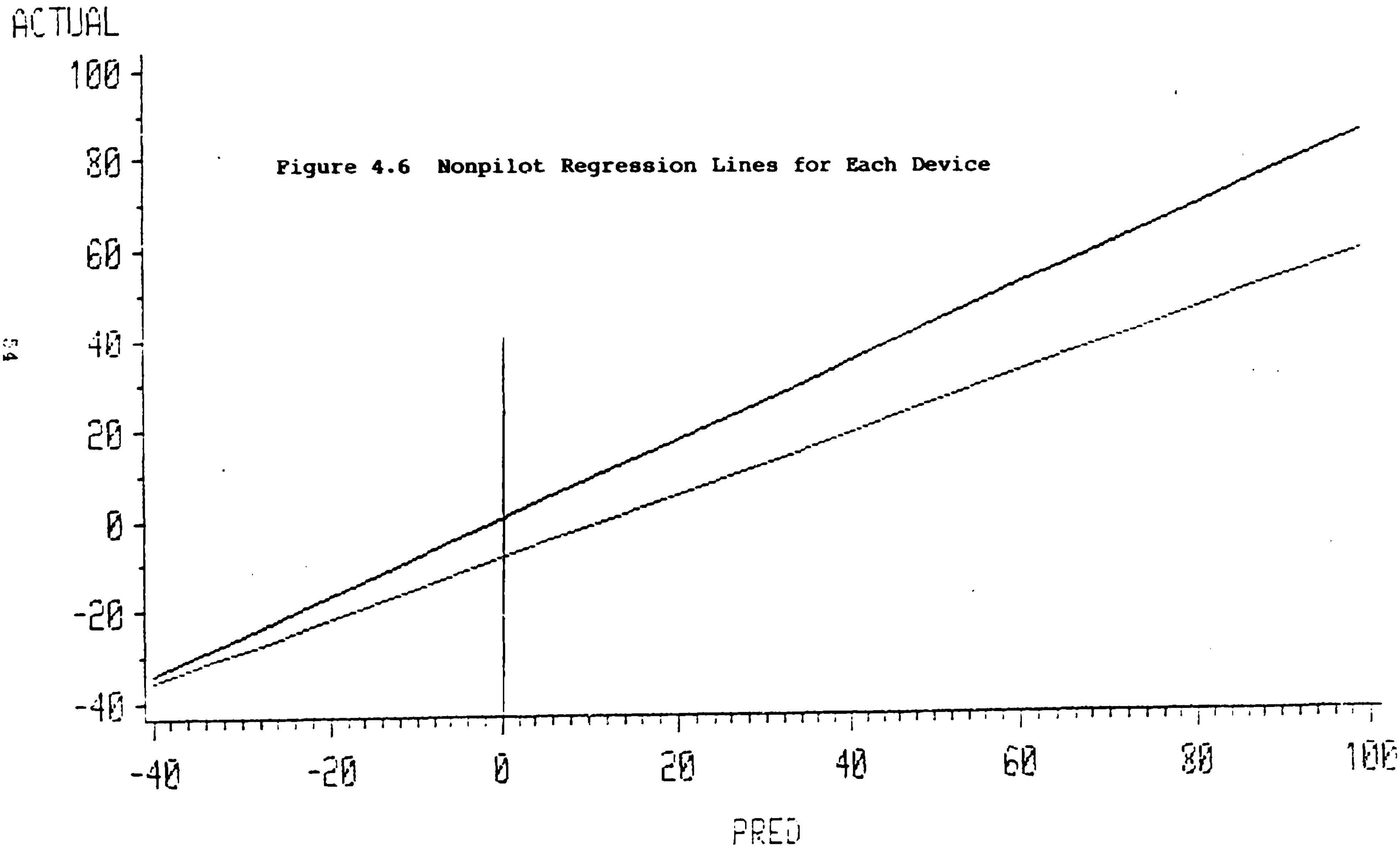


Figure 4.6 Nonpilot Regression Lines for Each Device

-0.293 and a slope of .843, while the line representing both groups on the attitude indicator intercepts at -8.798 and has a slope of .675. In comparing both of these lines to the predicted line which has an intercept equal to zero and a slope equal to 1.0, it is apparent that in all cases the observed slopes are not equal to 1.0. The downpointer's regression intercepts are not statistically different from 0.0, but the attitude indicator's intercept is statistically meaningful using a simple F-test.

Table 4.6 also shows the correlation values for each of the four different device-group lines. These values simply represent how well the actual values follow the predicted values.

4.3 INFERENTIAL STATISTICS

Considering the previous descriptive analyses, it seemed unfruitful to perform an elaborate inferential analysis. The use of such techniques as linear models was not required, but a simple ANOVA between several parameters of interest provides another means of data analysis supporting the results presented in the descriptive analysis section.

Table 4.7 presents the overall ANOVA summary considering all 1344 observations. The term df represents degrees of freedom, MSe stands for mean squared error, and F is the value of the F statistic.

Source	df	MSe	F
Pilot Status (PS)	1	450.24	0.53
Device	1	54105.84	96.14***
PS * Device	1	36.11	0.06

*** p<.001

Table 4.7 Analysis of Variance Summary

In this ANOVA, there is no statistical significance between pilots and nonpilots on either device (p=.4775). Additionally, the interaction between pilot status and device shows no significance (p=.8037). There is significance, however, between the devices; this significance is at the .0001 level.

Approaching this concept from a different perspective, consider the range of possible predicted values. This range goes from -30 to +80 degrees, in 10-degree increments, with a varying number of observations at each value. An ANOVA was performed at each of these predicted pitch values in order to determine the significance level, if any, between pilot status, device, and pilot status/device interaction. Table 4.8 presents the results. The term PV represents the predicted value from -30 to +80, the # symbol represents the number values in the data set, PS is the significance level of pilot status, DEVICE is the significance level of device differences, and PS*DEVICE is the interactive significance level.

PV	#	PS	DEVICE	PS*DEVICE
-30	32	.8957	.0015**	.4017
-20	64	.8925	.0237*	.5616
-10	96	.3497	.0030**	.3916
0	128	.8005	.0001**	.6619
+10	160	.2203	.0002**	.5137
+20	192	.5121	.0001**	.5428
+30	192	.0394*	.0001**	.7207
+40	160	.4002	.0001**	.8461
+50	128	.7168	.0001**	.7671
+60	96	.7446	.0003**	.9172
+70	64	.5994	.0001**	.6671
+80	32	.9571	.0040**	.8184

Table 4.8 Analysis of variance at different predicted value levels for pilot status, device, and pilot status*device interaction. (* $p<.05$, ** $p<.001$).

With an "alpha" level set at .05, Table 4.8 shows dramatically that at each and every predicted value level there is a significant difference between downpointer performance and attitude indicator performance. Table 4.8 also shows that at all predicted values, except +30, there is no significant difference between pilots and nonpilots. Finally, no significance occurred at any of the conditions testing for significance between the interaction of pilot status with device.

From the statistics presented, it is apparent that in quantifying the amount of the somatogravic illusion, the currently used canopy-mounted downpointer is superior in performance to the joystick-controlled attitude indicator. It is also concluded that there is no real difference between experienced pilots and nonpilots in their performance on either device, which supports previous studies. In the following chapter, some of the implications of this study and several suggestions for further research will be addressed.

CHAPTER V

SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

5.1 SUMMARY OF RESULTS

There are two primary results of this study:

1) One may reject the null hypothesis and conclude that there is a difference between the two devices. In quantifying the somatogravic illusion, the downpointer is clearly more accurate, in terms of the given model of the illusion, than the attitude indicator, and should, therefore, be retained as a measuring device.
2) There is no significant difference between the performance of pilots and nonpilots on either attitude indicator during exposure to the somatogravic illusion.

5.2 CONCLUSIONS

Since the USAFSAM is actively involved in research on spatial disorientation, they are expected to use these results to evaluate and improve their research methods, techniques, and equipment. In this regard, it is clear that the USAFSAM must continue to use the canopy-mounted downpointer as the primary data collection instrument on the Vertifuge, especially when considering illusions involving pitch and acceleration. There are many factors addressed in this chapter which have influenced these recommendations, implications, and suggestions for further research.

Not only does the downpointer perform measurably better at estimating the predicted values of the gravitoinertial force vector, it also costs less to construct and install, is easier to maintain, and is generally easier to use. The raw materials involved with the downpointer consist of a simple "extendable" stick attached to a multi-axis pivot. Calibration of the downpointer to record degrees deviation from a reference point (gravity) is performed easily. The attitude indicator device, on the other hand, consists of a Futaba joystick-controller valued at approximately $100 and a very expensive and difficult to obtain McDonnell-Douglas F-4 "Phantom" fighter aircraft attitude indicator.

The maintenance involved with the downpointer consists of returning it to its "clip-up" holder after use and calibrating it prior to data collection. The attitude indicator must be properly charged; both the joystick and the gyro-ball require separate charged battery packs, as well as connection to the main Vertifuge power supply. Of course, there is always the possibility that either battery pack might partially or completely drain prior to trial completion. The attitude indicator must also be calibrated prior to each trial and it should be removed and stored between periods of use.

Finally, the downpointer is inherently easier to use than the attitude indicator. "Point toward what you perceive to be straight down" is much more easily processed than, "Adjust the attitude indicator's horizon to what you perceive to be your position relative to the horizon." There is much less information processing involved with the downpointer; therefore, training is easier and faster. Training periods for the attitude indicator are consistently longer than for the downpointer, and nonpilot subjects were often initially confused by the premise of the inside-out display. Additionally, the task the subject performs is actually opposite to what a pilot would experience in true flight. Instead of adjusting the "stick" of the attitude indicator to "fly straight and level," the use of the attitude indicator asks that the subject move from the default position (straight and level) to a pitched attitude.

Another item of interest involves the role of proprioceptive cues in downpointer measurement. As previously stated, the suggested tendency of subjects to use proprioceptive cues more heavily and unrealistically on the downpointer led to the development of the attitude indicator. Quite possibly, the downpointer is too accurate and does not represent the actual effects of a somatogravic illusion in flight.

There are several important implications of this study. Some simply serve to reinforce results and conclusions from previous studies, while others serve to affect further Vertifuge experimentation.

The fact that experienced pilots are affected by the somatogravic illusion as much as naive nonpilots serves to support several previous studies (e.g., Wolfe and Cramer [1970]) and reiterate the importance of continuing spatial disorientation training. This result is important in establishing that there is no adaptation to the illusion through experience; even knowledge that it exists does not decrease the magnitude with which it is felt. This serves to promote an active spatial disorientation awareness program as the only effective manner with which to combat the potentially devastating effects of this problem.

5.3 RECOMMENDATIONS

Several recommendations for future study may be explored. First, it is necessary to determine the effect of ambient light in the Vertifuge compartment on performance with the downpointer. Realistically, even during a "dark-night takeoff" or severe weather conditions, there will be some ambient light in the cockpit, probably given off by the instruments. The only circumstance in which total darkness may occur is immediately after catastrophic instrument failure. This change in design would add more realism to the

Vertifuge's condition and would also possibly eliminate a hypothesis that explains the downpointer and attitude indicator differences simply as a matter of the presence of ambient light.

Another suggested study involves the performance of a specific subject subgroup. Within this subgroup there were two pilot subjects. Although their individual performances are not presented in the previous section, it is appropriate to mention them here. These two subjects were the only subjects with extensive experience in high performance fighter aircraft (F-15 and F-16). Both of them performed much worse than all other subjects on both devices. This could mean that they have learned to completely disregard their vestibular and proprioceptive inputs and that they would not hesitate to consult their instruments. Or more importantly, it may indicate some type of vestibular decrement of the otolith organs caused by extended long-term exposure to the g-shearing and spatially disorienting effects of the high performance environment. There are no longitudinal data available to support or refute this contention, as these aircraft have only been extensively introduced in the last 15 years.

A final proposed research topic involves the development of yet another measuring device utilizing the best characteristics of the downpointer and the attitude indicator. A side panel-mounted, spring-loaded downpointer would eliminate the ability of the subject to obtain "unfair" proprioceptive cues using the arm, while at the same time be inexpensive and easy to operate.

To summarize, it is necessary to promote an awareness of spatial disorientation at a level much higher than is being promoted and recognized today. With the increasing emphasis in this decade on G-induced loss of consciousness, spatial disorientation has seemingly assumed a backseat. This is in error. There are very important implications involved with spatial disorientation which range from the operational environment of an overworked pilot to the philosophical question of how man truly uses his senses to properly orient himself. There is a challenge to save lives, lower costs, and increase war-fighting capabilities. This challenge may partially be addressed through continued, dynamic, and operationally responsive research into spatial disorientation.

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APPENDIX A

INFORMED CONSENT

1. I, ______________________, hereby volunteer to participate as a test subject in the following experiment, "Spatial Disorientation in Humans", under the direction of Dr. Kent Gillingham, which has as its purpose the examination of the ways in which various senses (for example, vision, non-visual senses of balance, hearing, and touch) contribute to a person's orientation in space.

2. ____________________ has discussed with me to my satisfaction the reasons for this experiment and its possible adverse and beneficial consequences. I understand that I will receive a routine screening including visual and balance testing prior to being admitted to the study. I know that I will be given a task to perform while I am riding the Vertifuge. For example, I may be asked to "fly straight and level" or to point downward. I understand that additional information may be collected from me such as my level of attention or memory or the time it takes me to respond to certain signals. I know that some of the people who ride the Vertifuge develop symptoms of motion sickness which can range from mild queasiness to vomiting. I understand that one of the investigators will be present while I am riding the Vertifuge and the experiment will be stopped if I experience significant motion sickness. I understand that results of visual and health screening will be made available to me.

3. This consent is voluntary and has been given under circumstances in which I can exercise free power of choice. I have been informed that I may at any time revoke my consent and withdraw from the experiment without prejudice and that the investigators may terminate the experiment at any time regardless of my wishes.

4. I understand that before my use as a test subject, I must inform the principal investigator of any changes in my medical status. This information will include any medical or dental care/treatment received since my last use as a test subject.

______________________________   ______________
Volunteer's Signature   Date

______________________________   ______________
Organization, Grade, Duty Phone   Soc Security #

I was present during the explanation referred to above as well as during the volunteer's opportunity to ask questions, and hereby witness the signature.

______________________________   ______________
Witness   Date

APPENDIX B

VESTIBULAR EXAMINATION

Name: ____________

Date: ____________

SYMPTOM	PRESENCE	COMMENTS
Patient History		
1. Dizziness	______	____________
2. Deafness	______	____________
3. Tinnitus	______	____________
Physical Tests		
Vestibulo-spinal		
1. Walking (eyes open)	______	____________
2. Walking (eyes closed)	______	____________
3. Past-pointing (F-F)	______	____________
4. Sharpened Romberg (eyes closed)	______	____________
5. Stepping	______	____________
Vestibulo-ocular		
1. Gaze Nystagmus		
a. Spontaneous (8-point)	______	____________
b. Latent	______	____________
2. Positional Nystagmus		
a. Provoked	______	____________
b. Latent	______	____________
3. Rotational Nystagmus	______	____________

DIAGNOSIS: Normal__________ Other____________

APPENDIX C

SUBJECT: ____________ DATE: ________ DEVICE: ________

COCKPIT ANGLE	GRAVITOINERTIAL ANGLE					
-30						
RPM						
θy						
Øp						

COCKPIT ANGLE	GRAVITOINERTIAL ANGLE					
-20						
RPM						
θy						
Øp						

ANGLE	GRAVITOINERTIAL ANGLE					
-10						
RPM						
θy						
Øp						

ANGLE	GRAVITOINERTIAL ANGLE					
Ø						
RPM						
θy						
Øp						

ANGLE	GRAVITOINERTIAL ANGLE					
+10						
RPM						
θy						
Øp						

ANGLE	GRAVITOINERTIAL ANGLE					
+20						
RPM						
θy						
Øp						

ANGLE	GRAVITOINERTIAL ANGLE					
+30						
RPM						
θy						
Øp						

NOTES:

VITA

CENSUS: John F. Thompson was born on April 10, 1962, in Wooster, Ohio. His mother is Mrs. Janet L. Thompson of Dunedin, Florida. He is married.

TRAINING: John F. Thompson graduated from Indiana Area Senior High School, Indiana, Pennsylvania, in June, 1980. He received a Bachelor of Science degree and a commission as an officer in the U.S. Air Force from The United States Air Force Academy, Colorado Springs, Colorado, in December, 1984.

EXPERIENCE: From January, 1985 to August, 1987 he worked as an occupational analyst at the U.S.A.F. Occupational Measurement Center, Randolph Air Force Base, Texas. Since August, 1987 he has been a full-time industrial engineering student at St. Mary's University, San Antonio, Texas, on scholarship from the Air Force Institute of Technology.

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